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Magnetohydrodynamics (MHD) Engineering Test Facility (ETF) 200 MWe Power Plant

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Conceptual Design Engineering Report (CDER)

Volume IV — Supplementary Engineering Data

Gilbert / Commonwealth
Engineers / Consultants

September 1981

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Under Contract DEN 3-224

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Magnetohydrodynamics

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Gilbert / Commonwealth
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Reading, PA / Jackson, MI
Washington, D.C. / Oak Ridge, TN

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Under Interagency Agreement DE-AI01-77ET10769

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5.0 SUPPLEMENTARY ENGINEERING DATA

This section of the CDER contains background data used in the development of the physical and technical design, as well as plant costs and schedules, presented in the previous sections.

Included is a listing and discussion of major issues covering materials, components, systems, and techniques which could influence the final ETF design. Studies have been performed for some of the more significant issues and are contained in Section 5.2.2. Also included are outlines of plans for a performance assurance program and to perform an environmental analysis for the chosen site.

Detail design information for the various systems which comprise the ETF design is contained in the System Design Descriptions in Section 5.5.

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5.1 ISSUES

During the development of the conceptual design for the MHD-ETF, certain areas (issues) were identified as lacking sufficient definition due to the developmental nature of the ETF project. Each area was evaluated to determine its impact on the ETF design and possible options and specific recommendations were developed. The results of these evaluations have been tabulated into a list of issues for the CDER.

The Issues List is included as an attachment to this section of the CDER. A summary of the contents of this list is provided as follows:

Issue No.	Description	Sheet No.
1	Replace Steam Turbine Drives with Electric Motor Drives	1
2	Development of ETF Compatible High Technology Components (Interface Compatibility)	1
3	Part Load and Transient Analysis	2
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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OI
1	Replace Steam Turbine Drives with Electric Motor Drives	o Improve plant efficiency o Adopt standard main steam turbine generator design o Eliminate custom design steam turbine drives o Simplify plant arrangement o Facilitate plant startup with electric motor drives	o Maintain ste oxygen plant drives and d culty involv custom desig turbine gene required
2	Development of ETF Compatible High Technology Components (Interface Compatibility)	o Incompatibility with balance of plant and other high technology systems may force redesign to ensure compatibility o Scaling to ETF size could produce design problems that had not been considered, which in turn could result in potentially prohibitive problems for the ETF design o Scaling of ETF to produce compatibility with high technology components could compromise ability to realistically scale from ETF to commercial power plant size	o Redesign bal systems to b high technol o Resize the to be consi scale at whi technology c being develo

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OPTIONS	RECOMMENDATIONS	REMARKS
o Maintain steam turbines as oxygen plant compressor drives and determine difficulty involved in procuring custom design main steam turbine generator currently required	o At least replace boiler feed pump steam turbine drives by constant speed electric motor drives o Constant speed electric motors should be substituted for steam turbine drives for oxygen plant compressors o Part load heat rate and plant transient response should be determined with constant speed electric motor alternatives o Control methods for oxygen plant compressors should be verified and optimized with drive alternatives	o Switch to all electric drives will produce a major change to heat and mass balance diagram o Preliminary analysis of impact on design point performance issued in GAI report Engineering, Study 201(3), (GAI Ref. No. 120-195-201)
o Redesign balance of plant systems to be compatible with high technology components o Resize the ETF power output to be consistent with the scale at which the high technology components are being developed	o Attention should be given by the component developers regarding how design parameter selection will fit into the integrated plant design o Single person/group should coordinate the development of high technology components to ensure compatibility when integrated into one power cycle	

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OP
3	Part Load and Transient Analysis	o Results of analysis will contribute to the steady state and transient control logic definition and instrumentation requirements o Results will also help define impact that upset conditions will have on equipment, leading to definition of control steps required to protect the plant o Results will define part load operating parameters which will contribute to the equipment selections for base load operation and standby units	
4	ETF Instrumentation and Control	o Proper instrumentation and control logic required to protect personnel and equipment from transient perturbations o Need to have adequate control to efficiently operate the plant and to optimize equipment cyclical lifetime o Control equipment will have major impact on design, safeguards, and redundancy of major systems	o Specify the I&C througho system and a community" w ment ready w
5	Thermal Growth of Large Equipment and Piping During Plant Operation	o Lack of accommodation for thermal growth could seriously damage equipment	

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OPTIONS	RECOMMENDATIONS	REMARKS
	o Conduct a part load study to define steady state and transient operating parameters for the ETF	o Load following of topping to bottoming cycle must be characterized
	o Review malfunction analysis established in Issue No. 21 to determine system operational limits and responses	
	o Establish startup and shutdown procedure	
	o Conduct study as to system response to fuel flow change	
o Specify the requirements of I&C throughout the ETF power system and assume the "MHD community" will have equipment ready when needed	o Review the plant instrumentation and control systems to develop a system that can safely and efficiently control the plant operations, including the detection and control of malfunctions, as established in Issue No. 21	o Topping side major subsystems fall into similar categories of uncertainty regarding I&C
	o Review of MHD power train equipment should be conducted to ensure adequate arrangements for thermal growth	o Consideration has been given to the problem but no specific design analyses have been accomplished
	o The technology of the balance of plant equipment has been established and thermal growth problems are known but interfacing with the high technology components should be reviewed to account for thermal growth	

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OP
6	Electrical Isolation	o I^2R losses may be large o Lack of adequate isolation could be dangerous to personnel o Protection of isolation interfaces during transient and drop loads may be necessary	o Review advan ing at diffu
7	Alternate MHD Power Train Cooling	o Switching from feedwater cooling of combustor, channel, and diffuser to some alternate may introduce more system losses o Separate closed cooling loops with auxiliary heat sinks can offer improved cooling control of MHD components during upset conditions and during normal part load operation o Feedwater polishing equipment and piping for main feedwater stream can be reduced o Separate cooling loops would isolate MHD power train from main feedwater stream, providing more flexibility to maintain MHD power train components while preserving feedwater system integrity	o Review vario of feedwater ing systems. compromise M cooling syst bination of closed cooli
8	Seed Injection	o Improper seed injection could produce a nonhomogeneous seed flow, upsetting the channel operation o Inadequate monitoring, control, and feedback coordination with fuel and oxidant can impair proper plant control	o Slurry (wet has been de

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OPTIONS	RECOMMENDATIONS	REMARKS
o Review advantages of isolating at diffuser end	o In depth engineering study of electrical isolation should be conducted including effects of slag, seed, and coal flow o Effects of malfunction analysis, Issue No. 21, should be considered	o Need for isolation has been set but design work not initiated. Current design suggests isolation of the combustor and electric ground at the diffuser
o Review various combinations of feedwater and closed cooling systems. May produce a compromise MHD power train cooling system that is a combination of feedwater and closed cooling loops	o Impact of alternate cooling schemes on plant performance, cost, and complexity should be reviewed	o Closed loop channel cooling has been evaluated for the 100% rating point in a GAI report unnumbered, (GAI Ref. No. 040-086-001) FOLDOUT FRAME 2
o Slurry (wet seed) injection has been demonstrated	o Design and demonstrate the pressurized seed feed hopper and seed injection system o Design of screw conveyors, receiving hoppers, metering bunkers and pulverizers should be started with emphasis on seed flow measurement and control	o Dry injection into an MHD combustor has not been demonstrated under prototype conditions o Wet seed injection may reduce plant efficiency o For further data review the GAI report Engineering Study 304, (GAI Ref. No. 081-386-304)

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OP
9	Equipment Redundancy	o Not having adequate redundancy or alternate operational procedures could reduce plant availability, compromising objectives of ETF o Lack of adequate redundancy on certain components could produce plant upsets with potential to damage critical equipment	o Economic trad conducted to in providing are 3 50% or units more ec build in redu o Alternate mod e.g. oxygen storage coul into plant t dancy in lie multiplicity
10	Utilization of By-Product Gases and Secondary Waste Heat	o Increased utilization of nitrogen as transport gas, drying gas, inerting gas, etc. would allow increased use of flue gas for steam cycle heat addition o Recovery of secondary waste heat would reduce load on cooling tower system and provide more heat to steam cycle o Complexity of plant may be increased as attempts are made to use by-product streams heat and/or mass flow	o Implementati streams mass would be pre off of cycle versus incre plexity and o Where high l exist in was pump" techno used to brin "high grade"
11	ETF Heat Balance Improvement/ Optimization	o Improved bottoming cycle and plant efficiencies o Bottoming cycle configuration more like conventional power plant o Refine heat and mass balance to reflect data from high technology components design studies and from more detailed review of the balance of plant systems	o Incorporate performance the economic warrants

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OPTIONS	RECOMMENDATIONS	REMARKS
o Economic tradeoffs should be conducted to optimize approach in providing redundancy, e.g. are 3 50% or 2 100% rated units more economical way to build in redundancy o Alternate modes of operation, e.g. oxygen from liquid O_2 storage could be designed into plant to provide redundancy in lieu of incorporating multiplicity of units	o Review ETF design to ensure that appropriate equipment is redundant to protect critical plant components and provide required availability	o Equipment redundancy should be integrated with Instrumentation and Control studies, Issue No. 3, since redundant equipment selections can be influenced by I&C requirements o Malfunction analysis, Issue No. 21, will help to establish minimum redundancy requirements for equipment
o Implementation of by-product streams mass flow and heat would be predicated on tradeoff of cycle performance gain versus increased plant complexity and cost o Where high levels of enthalpy exist in waste streams "heat pump" technology could be used to bring streams to "high grade" enthalpy levels	o Review cycle configuration to determine what application can be made of nitrogen by-product gas and waste heat sources in plant o Review for future potential application the cogeneration or regeneration schemes that may improve total system performance	
o Incorporate the potential performance improvements if the economic tradeoff warrants	o Plant performance optimization should be reviewed in light of modification to design ambient conditions and new design data from both high technology systems and balance of plant systems	

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OP
12	Coal Drying Assessment	o Change to flue gas flow required for coal drying would increase/ decrease heating duty of L.T. economizer and ultimately the power generated by steam cycle o If alternate drying gas is selected (e.g. nitrogen), the power required to drive the ID fan in the Flue Gas Discharge System would increase	o Modify the fl required to of updated d design param o Attempt to i by-product s or waste hea replace flue drying
13	Recycle Seed	o Performance of the topping cycle will be influenced to some extent by the chemical, physical and flow characteristics of the recycled material o The size distribution of the seed leaving the HR/SR may be such that pneumatic transport may be difficult o Transportation of spent seed by truck will provide operational flexibility but will result in high labor costs	o Continue to and performan through seed o Install size equipment at the HR/SR sp o Transport sp by means of pneumatic co
14	Impact of New Magnetic Field Exclusion for Personnel Access	o Components requiring frequent maintenance are to be located outside of the 0.01 tesla magnetic field boundary. This requires changes to the ETF plot plan and plant layout drawings o Only approved personnel are allowed within the 0.0005 tesla magnetic field boundary. Time limits for approved personnel in the various magnetic field zones are specified in the National Magnet Laboratory Specification A4442, Rev. D.	

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OPTIONS	RECOMMENDATIONS	REMARKS
o Modify the flue gas flow required to meet constraints of updated drying system design parameters o Attempt to incorporate a by-product stream mass flow or waste heat to supplement/replace flue gas for coal drying	o Review the technique used for coal drying to insure that a practical, safe system is selected for the ETF design	
o Continue to base ETF design and performance on once through seed flow o Install size reduction equipment at the outlet of the HR/SR spent seed hoppers o Transport spent seed on-site by means of a mechanical or pneumatic conveyor system	o Carry out a chemical equilibrium study to establish the composition of the topping cycle flow stream for the o Decide whether or not to install size reduction equipment after the HR/SR has been designed and the physical condition of its products specified o Carry out a technical, environmental and economic study to decide whether trucks or conveyors should be used for recycling spent seed from the spent seed silos	o The chemical equilibrium study should provide input data for a revised heat and material balance. See issue 11 o The physical condition of the seed may have been an impact on the cost of seed dissolution (issue 22) and on the materials handling equipment selected for recycling spent seed o The GAI report Engineering Study 304, (GAI Ref. No. 081-386-304) may have some impact on Recycle Seed
	o The alternative plant layout and equipment arrangement generated by the new magnetic field exclusion requirements should be incorporated into the EFT plant design	o Performance of the ETF plant is not affected by the new magnetic field exclusion requirements o The impact of the new magnetic field exclusion guidelines on the ETF configuration and layout has been evaluated in a GAI report Engineering Study 305, (GAI Ref. No. 071-368-305)

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OPT
14	Impact of New Magnetic Field Exclusion for Personnal Access (Cont'd)	o Unapproved personnel are limited to areas where the magnetic field is less than 0.0005 tesla (no time limit). This requires relocation of the security fence south of the plant site and the installation of numerous caution signs along the entire length of the security fence that encompasses the plant island. o The MHD Building crane is to be repositioned to a new storage location at the maximum possible distance from the magnet centerline.	
15	Alternate Methods of Channel Replacement	o Arrangement and support of MHD power train components will be influenced by technique to be employed for channel removal o Plant availability may be affected by removal method	o Remove diffus o Roll apart sp o Roll aside ma
16	Secondary Flue Gas Ductwork	o Fan and power requirements o Equipment cost o Installation cost	o Multiple stac
17	Environmental Analysis	o Size of cleanup system, stoichiometry, amount of K_2CO_3 required, residence time for flue gas and temperatures in HR/SR, and auxiliary equipment will be affected by environmental analysis	o Emerging tech initial exemp meeting EPA r may allow opp equipment req be developed

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OPTIONS	RECOMMENDATIONS	REMARKS
o Remove diffuser o Roll apart split-magnet o Roll aside magnet	o Roll apart split-magnet arrangement requires least calendar hours and man hours to replace channel o Since channel total down time o Effects are not our of line with other components, replacement procedures and subsystem arrangements should be predicated on overall system design and performance criteria	o Channel outage times and effects on system availability do not impose undue penalties for the reference case or any of the alternatives reviewed. o This Arrangement and Support Issue was addressed in GAI report Engineering Study 306(2), (GAI Ref. No. 071-361-306)
o Multiple stack	o Review ducting system to determine feasibility and desirability of a multiple stack exhaust for ETF	o This plant availability was addressed in GAI report Engineering Study 306(1), (GAI Ref. No. 071-361-306)
o Emerging technologies initial exemption from meeting EPA requirements may allow opportunity for equipment requirements to be developed	o An environmental analysis study must be conducted to support the ETF conceptual design	

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	
18	Performance Assurance Program Plan	o Performance Assurance plan could affect cost o Performance Assurance plan will guide the design and development of plant components and systems	
19	Facility Cost Analysis	o Optimization of major costs has not been included	o Improved o Improved projected tion date details
20	MHD Electrical Power Distribution	o Performance and cost of major MHD electrical systems from the channel to the bus bar are affected by changes to any of the components	o Maintain o Redesign distribut complexit reduction mance and
21	Malfunction Analysis	o Possible unsafe operating modes or conditions will be identified o Plant performance and availability could be affected o Additional instrumentation and control for malfunction response may be required o Strengthening of equipment or added personnel protection may be required	

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OPTIONS	RECOMMENDATIONS	REMARKS
	o A Performance Assurance plan should be developed	o Currently an outline of a Performance Assurance plan has been developed
o Improved plant arrangement o Improved equipment costs projected to plant completion date details	o Assessment of capital costs for the commercial phase of operation should evolve from firmer definition of topping side design and construction details	o Operating and maintenance costs of the ETF during commercial operation should be consistent with those of new coal fired conventional plants when correlated on an equivalent basis
o Maintain present design o Redesign the electrical power distribution system to reduce complexity at a possible reduction in channel performance and efficiency	o A coordinated study of the MHD electrical power distribution system should be conducted	o MHD electrical power distribution analysis involves several high technology components and study should be coordinated by one responsible group to insure maximum compatibility and consistency
	o A malfunction analysis should be conducted	

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	OP
22	Seed Reprocessing	o On site seed reprocessing will affect plant layout o An increase in plant auxiliary power requirement and decrease in plant efficiency would be expected o Net improvement in plant economics is possible	o Maintain pre off site see seed purchas o Provide on s cessing by m the followin a. The Resou Co. (RCC) process b. A modifie RCC proce c. A seed rep other than process
23	Utilization of Channel End Regions - Theoretical Channel design analysis does not include channel sections in magnetic fields between 0 to 4.0 tesla, and 3.5 to 0 tesla	o Utilization of these channel end regions will increase electrical power quantity delivered to the grid o Gas stream exiting the Channel will have reduced enthalpy. Additional low-grade heat must be accepted by the bottoming plant o The Power Plant Heat and Mass Balance will be affected and Component sizing and system configuration may be affected	o ETF design i regions to p lating curre o Extract addi from end reg
24	Multidimensional Channel Analysis - Theoretical MHD Channel and generator analysis is one dimensional. Multidimensional analysis is desired to confirm design assumptions FOLDOUT FRAME	o Results may modify design of Channel and diffuser o ETF performance may be affected somewhat	

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OPTIONS	RECOMMENDATIONS	REMARKS
o Maintain present options of off site seed reprocessing or seed purchase o Provide on site seed reprocessing by means of one of the following: a. The Resources Conservation Co. (RCC) Engel-Precht process b. A modified version of the RCC process c. A seed reprocessing process other than the Engel-Precht process	o An investment analysis should be carried out based on the results of Engineering Study 304 (GAI Ref. No. 081-386-304) - (On site Integration of the RCC Modified Engel-Precht Seed Reprocessing System into ETF). o A detailed engineering design and evaluation study should be carried out on the RCC Engel-Precht process with the sodium removal module deleted. o Pilot plant tests are needed for the RCC Engel-Precht process to reduce the technical and economic risks of development	o The investment analysis study, detailed engineering design and evaluation study, and the pilot plant test study should be carried out sequentially. o For further data review the GAI report Engineering Study 304 (GAI Ref. No. 081-386-304)
o ETF design insulates end regions to prevent circulating currents o Extract additional power from end regions	o This integration of Magnet and Channel performance should be examined specifically in areas of predictions of component performance and development data o Evaluate net effect on plant performance	o For further data review paper No. AIAA-82-0325 to be presented at AIAA 20th Aerospace Science Conference Jan. 1982 by S. Wang (NASA)
	o This work be included in component development. After component data is developed the component data should be integrated into the Power Train System	FOLDOUT FRAME 2

NASA MHD-ETF CO
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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	
25	Channel Mach Number - MHD Power Train utilizes subsonic flow. A Supersonic Channel application in ETF appears creditable and merits analysis	o Requirement for a lower magnetic field strength will reduce magnet design performance and economic requirements o Reduced magnetic field strength will reduce personnel and equipment exclusion areas o Supersonic flow reduces probability for acoustic instabilities in Power Train o There will be some loss in plant performance	o Subsonic o Supersoni
26	Power Train Testing - requirements must be defined to establish the facility demands	o Specific requirements may involve specialized equipment and may affect equipment size and system configuration. The resulting engineering compromises may affect Plant performance and operation	o Perform c testing a o Perform t ETF o Perform t faciliti

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OPTIONS	RECOMMENDATIONS	REMARKS
o Subsonic Channel o Supersonic Channel	o Theoretical analysis should be performed in this area to establish values for relative costs and plant performance	o Most testing to date has been on supersonic channel o For further data review NASA paper No. AIAA-82-0325
o Perform component and system testing at the mfg facilities o Perform testing only at the ETF o Perform testing at both mfg facilities and ETF	o Review CDIF testing program to identify probable test requirements at 500 MWe o Estimate impact of testing at ETF on schedule, equipment, Plant performance, hazards, etc. Estimate cost of off-site testing o Test requirements at ETF should be established by programmatic decisions. Consider responsibility if the component failure delays plant operation	o Meaningful testing for evaluation of MHD subsystems will required bypass quench ducting and major heat removal systems of the bottoming side

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ISSUE NO.	DESCRIPTION/BACKGROUND INFORMATION	IMPACT ON ETF DESIGN	
27	Regenerative Combustor Cooling - The ETF combustor is cooled with boiler feedwater. The ETF design may be simplified by using the combustor and nozzle tube walls to preheat the oxidant for the high temperature combustion process.	o The Intermediate Temperature Oxidant Heater (ITOH) and the high temperature oxidant piping to Combustor would be eliminated. o Possibility of acoustic upsets in the oxidant supply lines to the Combustor would be reduced. o Performance of both topping and bottoming cycles are affected o Only minor changes are required to the ETF configuration and plant layout	

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OPTIONS	RECOMMENDATIONS	REMARKS
	o The concept of a regenerative combustor for preheating the oxidant should be incorporated into the ETF plant design. o Further study is required to evaluate the total economic impact of regenerative combustor cooling on the ETF design	o GE has developed a 5 MWt regeneratively-cooled combustor for closed-cycle MHD applications o The impact of regenerative combustor cooling on the ETF design has been evaluated in a GAI report Engineering Study 307, (GAI Ref. No. 091-429-307) o Reduced power output of the channel could permit reduction of the inverter capacity FOLDOUT FRAME 2

5.2 BACKGROUND DATA

The data contained in this section consists of study results which provide the design antecedents for the basic concepts of a 200 MWe, oxygen enriched, combined cycle MHD power plant; pertinent studies which were performed to resolve major issues affecting the final ETF design; and supplemental cost and schedule data for the high technology equipment.

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5.2.1 Design Antecedents

A study was conducted to analytically evaluate a 200 MWe power plant consisting of a MHD topping cycle integrated for combined cycle operation with a steam power plant. The results of this study were used to generate a GAI letter report which summarizes the design and performance requirements for the MHD-ETF power plant. This report, "200 MWe Net Output - Magnetohydrodynamics/ Steam Power Plant - Heat and Mass Balance Diagram Description," dated February, 1981, is included as an attachment to this section of the CDER.

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
SUBTASK WORK ORDER 202

200 MWe NET OUTPUT
MAGNETOHYDRODYNAMIC/STEAM POWER PLANT
HEAT AND MASS BALANCE DIAGRAM DESCRIPTION

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

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FEBRUARY, 1981

FOREWORD

This power plant analysis report was previously Appendix A to Revision 1 (dated 3 Oct. 1980) of the Design Requirements Document (DRD) for the Magnetohydrodynamics Engineering Test Facility (MHD-ETF) which is currently under conceptual design for the Department of Energy. It had been included in the DRD to provide technical backup material for the design. The DRD has since been revised, and in the process, the need for Appendix A was eliminated. The former Appendix A is being issued as a letter report to document the engineering changes that were included in the current updated MHD ETF conceptual design heat and mass balance diagram (Dwg. 8270-1-540-314-001, Revision B).

ABSTRACT

A 200 megawatt electrical (MWe) net output magnetohydrodynamic (MHD) power plant has been conceptually defined for consideration as the Engineering Test Facility (ETF). The plant has been scaled-up from a previous ETF design of a 166 MWe net output MHD plant.

The MHD cycle is fired with subbituminous coal from the Montana Rosebud seam and oxygen enriched air (30 mole percent oxygen). The enriched air is preheated to 1100°F in a direct fired metallic recuperative heat exchanger.

Component and systems analyses determine a performance criteria for the major components. The MHD generator produced a gross output of 87.1 MWe and its exhaust provided the thermal input for the steam bottoming cycle. A 1815 psia/1000°F/1000°F reheat steam plant was chosen for the bottoming cycle. The combined cycle produces 202 MWe net output from 532 MWt of coal input at a plant efficiency of 38.0 percent (a heat rate of 8,972 Btu/KWh).

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1.0 Introduction

This study analytically evaluates a 200 MWe net output, oxygen enriched MHD topping cycle integrated for combined cycle operation with a steam plant. This MHD cycle is fired with subbituminous coal from the Montana Rosebud seam and air enriched to 30 mole percent oxygen and preheated to 1,100°F. The steam plant is an 1,815 psia/1,000°F/1,000°F reheat cycle. The MHD heat recovery system generates all of the steam required by the turbine. Major MHD and steam plant pumps and compressors are driven by steam turbines. Major portions of this study were prepared under U.S. Department of Energy Contract No. ET-78-C-01-2688.

1.1 Scope

The scope of this study is to provide:

- o the identification of an ETF system,
- o a preliminary performance evaluation of that system, and a
- o documentation source for subsequent revisions.

1.2 Study Ground Rules

The ground rules under which this study was performed are:

a. Montana Rosebud coal is used as the fuel;

b. the nominal power plant net output is 200 MWe;

c. the oxidant preheat temperature is 1,100°F, with the oxidant enriched to 30 mole percent oxygen;

d. local ambient conditions are 42°F, 13.0 psia at a specific humidity of 0.0037 lb of moisture per pound of dry air;

e. main condenser pressure is 2.0 in Hga at the design point.

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2.0 MHD Topping Cycle

The major subsystems of the MHD topping cycle are:

- Coal Preparation
- Oxidant Delivery
- Oxidant Preheater,
- Combustor,
- MHD Power Loop,
- Heat Recovery and Seed Recovery (HR/SR)
- Seed Reprocessing

These subsystems, with the exception of seed reprocessing, are described below.

2.1 Coal Preparation

Montana Rosebud coal with a moisture content of 22.7 percent is crushed, introduced into the pulverizers, and then dried to 5 percent moisture using 480°F exhaust gas. The drying gas to coal mass flow rate is approximately 3-to-1. The dry pulverized coal at 150°F is separated from the drying gas in the mechanical collectors and baghouse and is transported to the MHD combustor by a pressurized exhaust gas bleed.

2.2 Oxidant Delivery

An energy efficient on-site oxygen plant produces the pressurized 70 mole percent oxygen which is blended with pressurized air to form the 30 mole percent oxygen combustion oxidant. The oxygen plant was scaled from plants in detailed oxygen production studies (Reference 1). The oxygen plant requires 221 kWh/ton equivalent pure O_2 of compression power (at 58.6 psia delivery pressure) to provide the cryogenic separation of the oxygen. The oxygen plant

with a capacity to produce 1,600 tons of equivalent pure oxygen per day is needed to meet the oxidant requirements of this 200 MWe MHD plant.

The equivalent pure O_2 is defined as the amount of pure O_2 added to normal dry air (which contains 21.0 mole percent O_2) to produce a 70 mole percent O_2 mixture. Table 2.4.1 shows the air and oxidant compositions used in the ETF design analysis.

Two compressor systems are required to deliver the pressurized and enriched oxidant to the combustor. These systems are: a highly intercooled, steam turbine driven compressor to supply air to the air separation unit, and an uncooled steam turbine driven compressor that pressurizes the blended mixture of ambient air and the 70 mole percent pure O_2 product gas from the air separation unit. These compressors were estimated to require 12,275 kW, and 23,448 kW power, respectively.

2.3 Oxidant Preheater

The oxidant preheater is designed to heat the pressurized combustion oxidizer to 1,100°F. The heater is constructed of high temperature, corrosion resistant tubes designed to withstand the pressure differential between the oxidant and the hot MHD exhaust gas. The choice of 1,100°F preheat for these studies is considered reasonable for a reliable, cost-effective unit that is to operate in the corrosive and erosive environment of the MHD exhaust.

2.4 Combustor

The combustor is pressurized and will operate at 90 percent stoichiometry, 65 percent slag rejection, with 1 percent potassium in the combustion gas, burning the pulverized coal described in Table 2.4.2. A detailed assessment of combustor design was not performed during this study. Combustor heat loss to the feedwater cooled waterwalls was assumed to be 24.8 MWt, 4.7 percent of the coal HHV input.

TABLE 2.4.1
AIR AND OXIDANT COMPOSITIONS

Mole Percent

	Dry Air	Ambient Air*	70% O_2 ASU Product	30% O_2 Oxidant
Nitrogen, N_2	78.084	77.626	26.88	68.160
Oxygen, O_2	20.950	20.827	70.00	30.000
Argon, Ar	0.934	0.928	3.12	1.336
Water Vapor, H_2O	0	0.587	0	0.478
Carbon Dioxide, CO_2	0.032	0.032	0	0.026
	100.000	100.000	100.000	100.000

Weight Percent

	Dry Air	Ambient Air*	70% O_2 ASU Product	30% O_2 Oxidant
Nitrogen, N_2	75.519	75.238	24.152	65.111
Oxygen, O_2	23.144	23.062	71.850	32.737
Argon, Ar	1.288	1.283	3.998	1.820
Water Vapor, H_2O	0	0.368	0	0.293
Carbon Dioxide, CO_2	0.049	0.049	0	0.039
	100.000	100.000	100.000	100.000

Molecular Weight

Nitrogen, N_2	--	28.013
Oxygen, O_2	--	31.999
Argon, Ar	--	39.948
Water Vapor, H_2O	--	18.016
Carbon Dioxide, CO_2	--	44.0101

* Based on

Tdry = 42F
Twet = 36F

TABLE 2.4.2

ETF COAL PROPERTIES

COAL: RANK: Subbituminous B

PROXIMATE ANALYSIS:	Weight* Percent As Received
Moisture	22.7
Volatile Matter	29.4
Fixed Carbon	39.2
Ash	8.7
	100.0

ULTIMATE ANALYSIS:	Weight* Percent As Received (base)	Weight Percent As Fired (derived)	Weight Percent Dry (derived)
Carbon	52.13	64.0666	67.4385
Hydrogen	3.46	4.2523	4.4761
Oxygen	11.36	13.9612	14.6960
Nitrogen	0.79	0.9709	1.0220
Sulfur	0.85	1.0446	1.0996
Ash	8.71	10.7044	11.2678
Moisture	22.70	5.0000	0.
	100.00	100.0000	100.0000
Higher Heating Value, Btu/lb	8,920	10,962.5	11,539.5

ASH ANALYSIS:	Weight* Percent
SiO_2	38.68
Ai_2O_3	17.80
Fe_2O_3	5.25
TiO_2	0.72
P_2O_5	0.41
CaO	11.32
MgO	4.12
Na_2O	3.19
K_2O	0.51
SO_3	18.00
	100.00

Initial Deformation Temperature, °F	2,190 ± 230
Softening Temperature, °F	2,230 ± 240
Fluid Temperature, °F	2,280 ± 240

* Source: Letter Rigo (NASA/LeRC) to Guy (G/C); "ETF Coal Properties"; February 1, 1980.

Properties of the MHD channel plasma used for these evaluations were calculated under the following assumptions:

a) 5 percent moist Montana coal (see Table 2.4.2) is used as fuel.

b) one percent potassium by weight is injected into combustor discharge gas.

c) oxidant contains 30 mole percent oxygen.

d) combustion occurs at 90 percent stoichiometry.

e) 65.3 percent of the original coal ash is removed as slag.

f) chemical equilibrium is attained.

The characteristics of this plasma were calculated by Gilbert Associates' CEC computer code. The resulting combustor inputs and outputs are:

TABLE 2.4.3

COMBUSTOR INPUTS AND OUTPUTS

	Per Pound Coal Feed lb/lb Coal	For 532 MWt Coal Input lb/hr
Coal feed (5 percent moist)	1.000000	165,622
Coal transport gas	0.033003	5,466
30 mole percent O_2 oxidant feed	5.239990	867,852
K_2CO_3 feed	0.049585	8,212
K_2SO_4 feed	0.078598	13,018
Slag rejected	0.069574	1[illegible],523
Channel gas produced	6.331060	1,048,569

Figure 2.4.1 presents the Mollier chart of this plasma. Figure 2.4.2 indicates the plasma electrical conductivity.

K_2CO_3 is used for sulfur capture. To assure sulfur capture, K_2CO_3 in excess of stoichiometric K_2CO_3 was supplied such that 1.1 moles of K_2CO_3 was injected for each mole of sulfur in the coal.

Thus K_2CO_3 injection was set at 0.04959 pounds for each pound coal. K_2SO_4 was used as the additional seed material to provide the required one percent potassium by weight in the MHD exhaust gas. This results in a K_2CO_3/K_2SO_4 mass ratio of 0.631:1.

The combustion flame temperature attained by this plasma is a function of the following parameters:

a) oxidant preheat of 1,100°F

b) combustor inlet pressure of 70 psia

c) coal temperature of 150°F

d) seed temperature of 150°F

e) combustor heat loss of 4.67 percent of coal HHV (= 10,962.5 Btu/lb)

f) combustor pressure drop of 5.0 percent

For the design combustor discharge pressure of 4.516 atm abs, the flame temperature is 4,381°F (2,690K).

FIGURE 2.4.1
MOLLIER DIAGRAM FOR COMBUSTION PRODUCTS

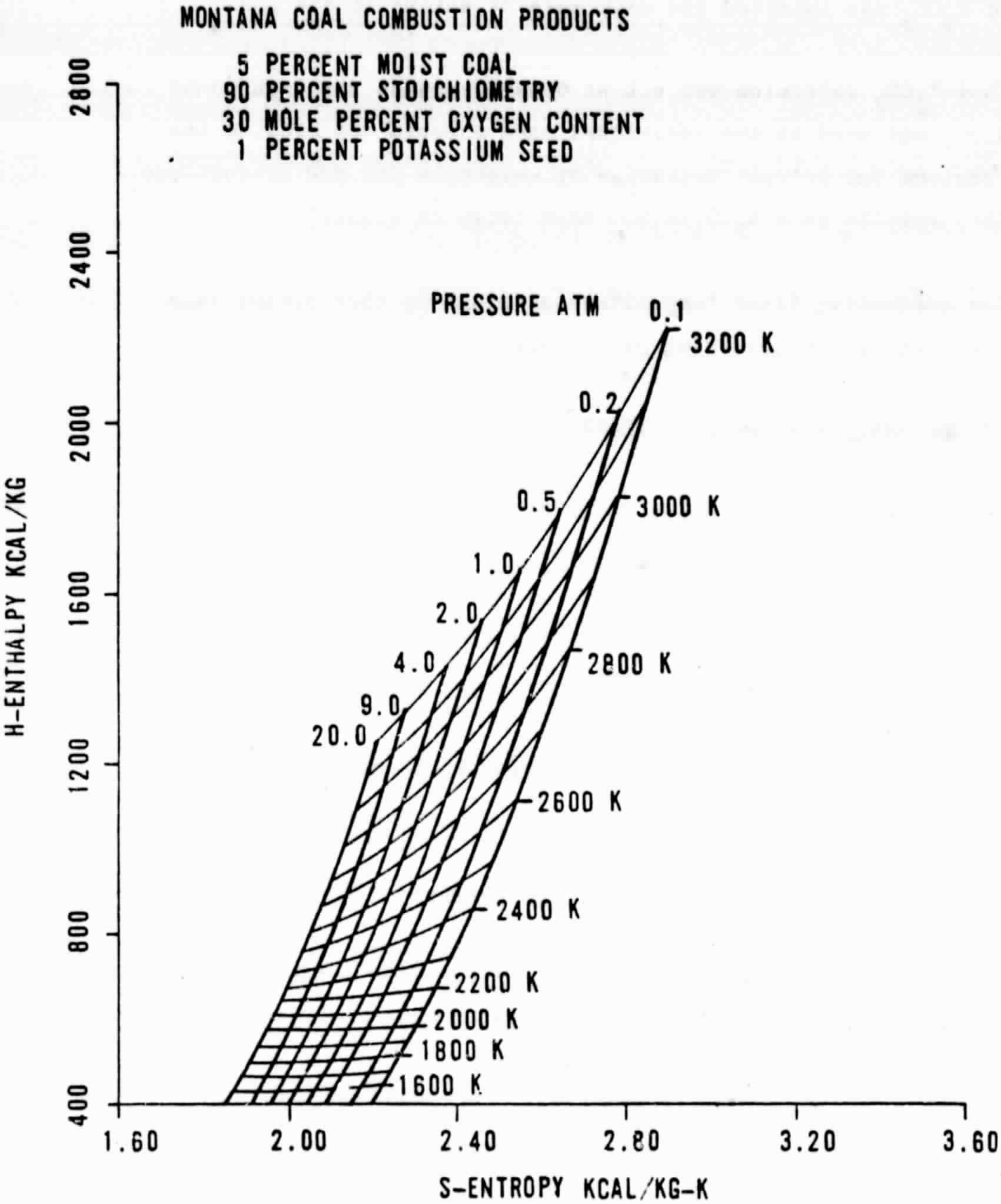
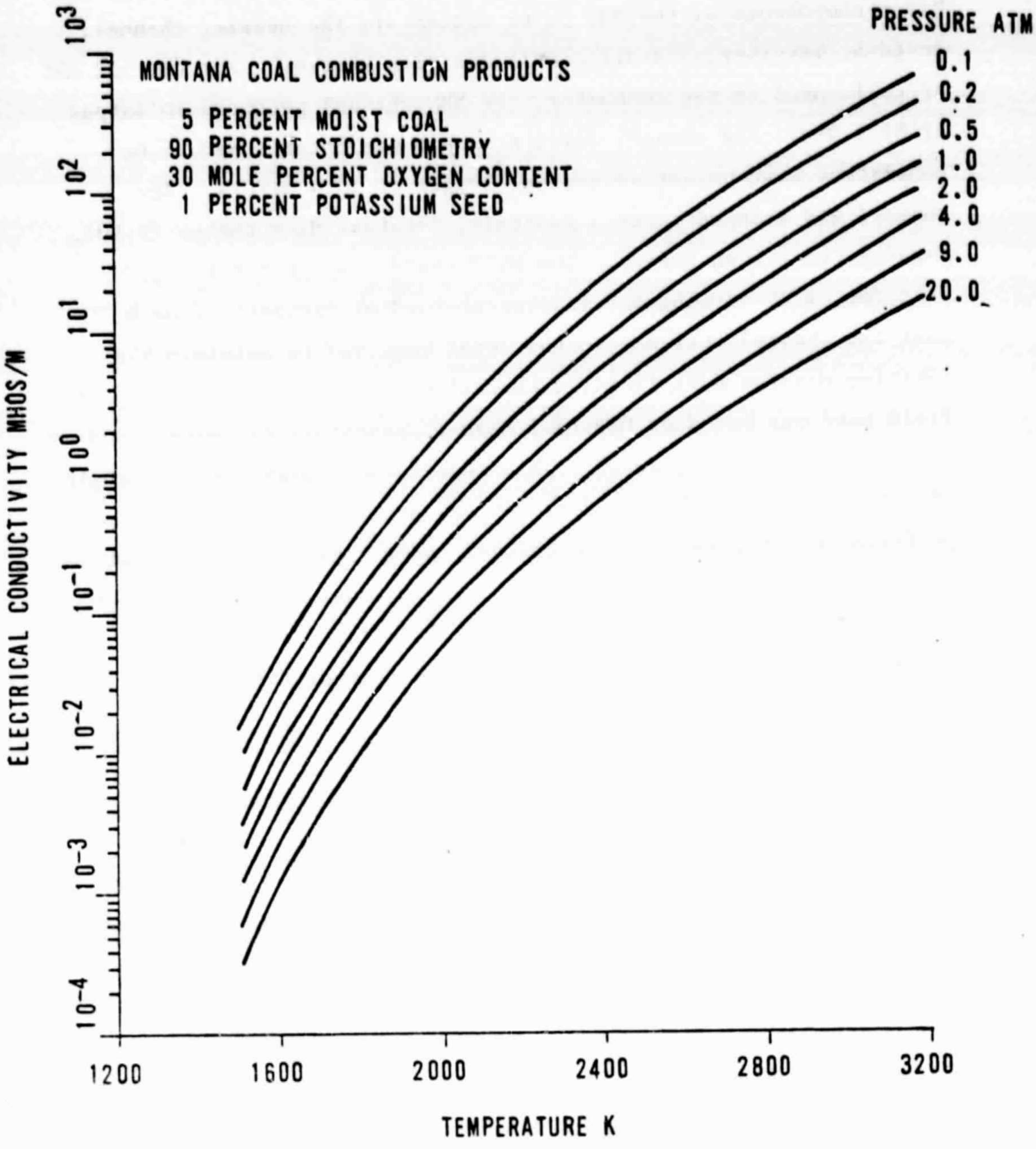


FIGURE 2.4.2
ELECTRICAL CONDUCTIVITY VS. TEMPERATURE



2.5 MHD Power Loop

Major components of the MHD power system are the nozzle, channel, dc-to-ac inverter, and diffuser/transition section. For the 532 MWt of coal input to the combustor, the MHD channel produces an output of 87.1 MWe. The channel inlet pressure was established to be consistent with an active channel length of 12.1 meters. The channel was assumed to be a subsonic, constant Mach number (0.90), Faraday connection design. The Hall field was limited to 2,500 volts/meter by varying the transverse loading parameter from 0.75 near the channel entrance to the level required to maintain the limiting maximum Hall field further along the channel. The magnetic field used was based on National Magnet Laboratory estimates, and is illustrated in Figure 2.4.3. This magnet has a peak field strength of 6 tesla. Figure 2.5 illustrates the geometry, flow rates, and performance estimated for the channel under these conditions, while Table 2.5 summarizes these results. The channel was assumed to be water cooled with 214°F feedwater that is allowed to attain a maximum water temperature of 236°F before leaving the channel cooling loops.

The diffuser and transition sections are designed to decelerate the high velocity gases leaving the channel to acceptable levels (approximately 30 meters/second) at the entrance to the heat and seed recovery section. The transition section, which connects the diffuser and steam generator, is a constant area duct with a cross sectional area large enough to complete the deceleration. For this application, the diffuser/transition section is expected to have a pressure recovery coefficient equal to 0.46 and to discharge into the radiant boiler at ambient pressure (13.0 psia). Diffuser heat loss was estimated to be 26.5 MWt.

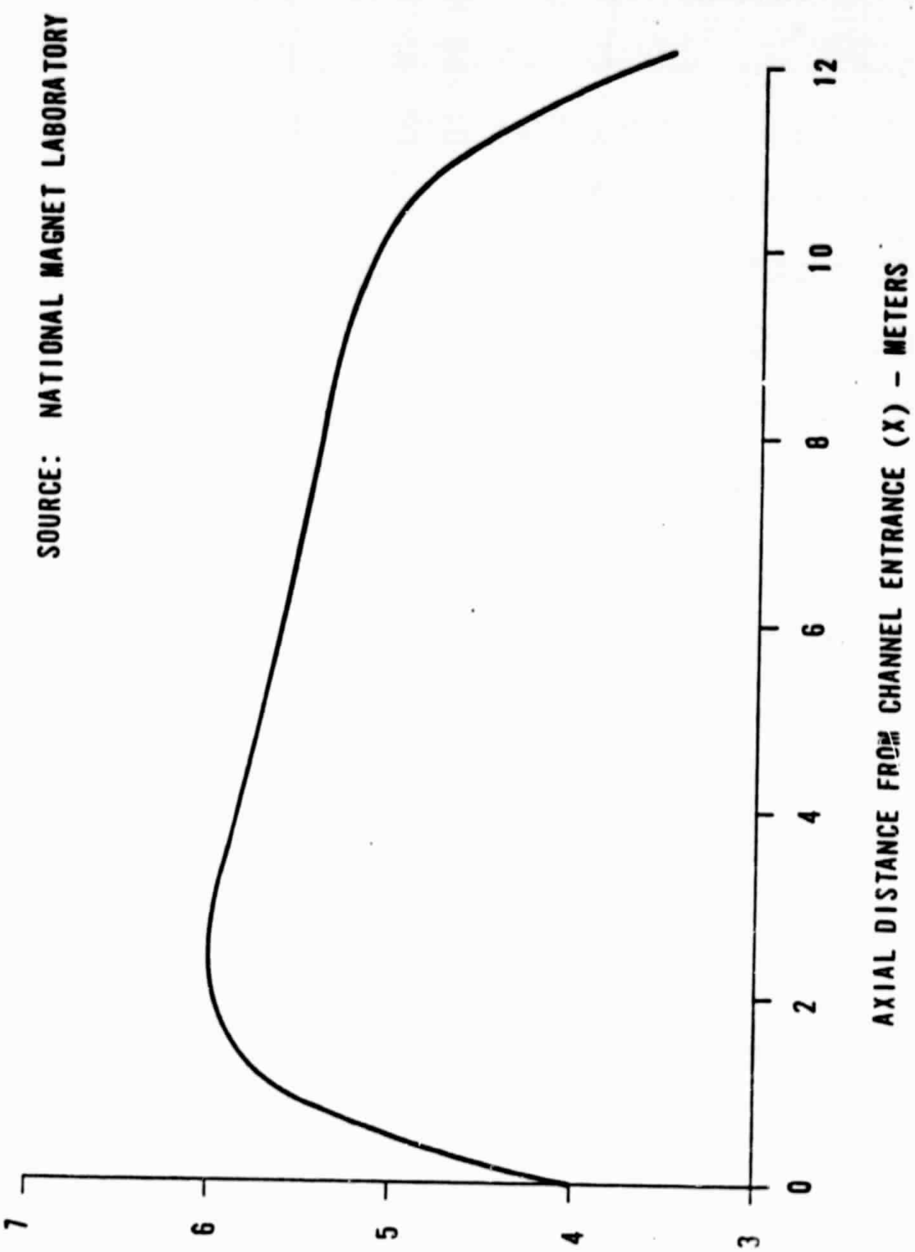


FIGURE 2.4.3
MAGNETIC FIELD STRENGTH VS. CHANNEL LENGTH

30 MOLE PERCENT OXYGEN 1,100°F PREHEAT 90 PERCENT STOICHIOMETRY

MAX MAG FIELD STRENGTH:	6.00	TESLA	NOZZLE HEAT LOSS:	(INCLUDED WITH COMBUSTOR)	
MAX HALL TEMPERATURE:	1800	DEG K	CHANNEL HEAT LOSS:	22.89	MW
MAX ELEC FIELD STRENGTH:	2500	V/M	DIFFUSER HEAT LOSS:	26.53	MW
GENERATOR POWER OUTPUT:	87.09	MW	TOTAL HEAT LOSS:	49.42	MW
EXTRACTION RATIO:	0.173		THERMAL INPUT:	532.00	MW

W = FLOW - KG/S
T = TEMPERATURE - K
P = PRESSURE - ATM
H = ENTHALPY - KCAL/KG
A_T = TOTAL AREA - M^2
V = VELOCITY - M/S
M = MACH NUMBER

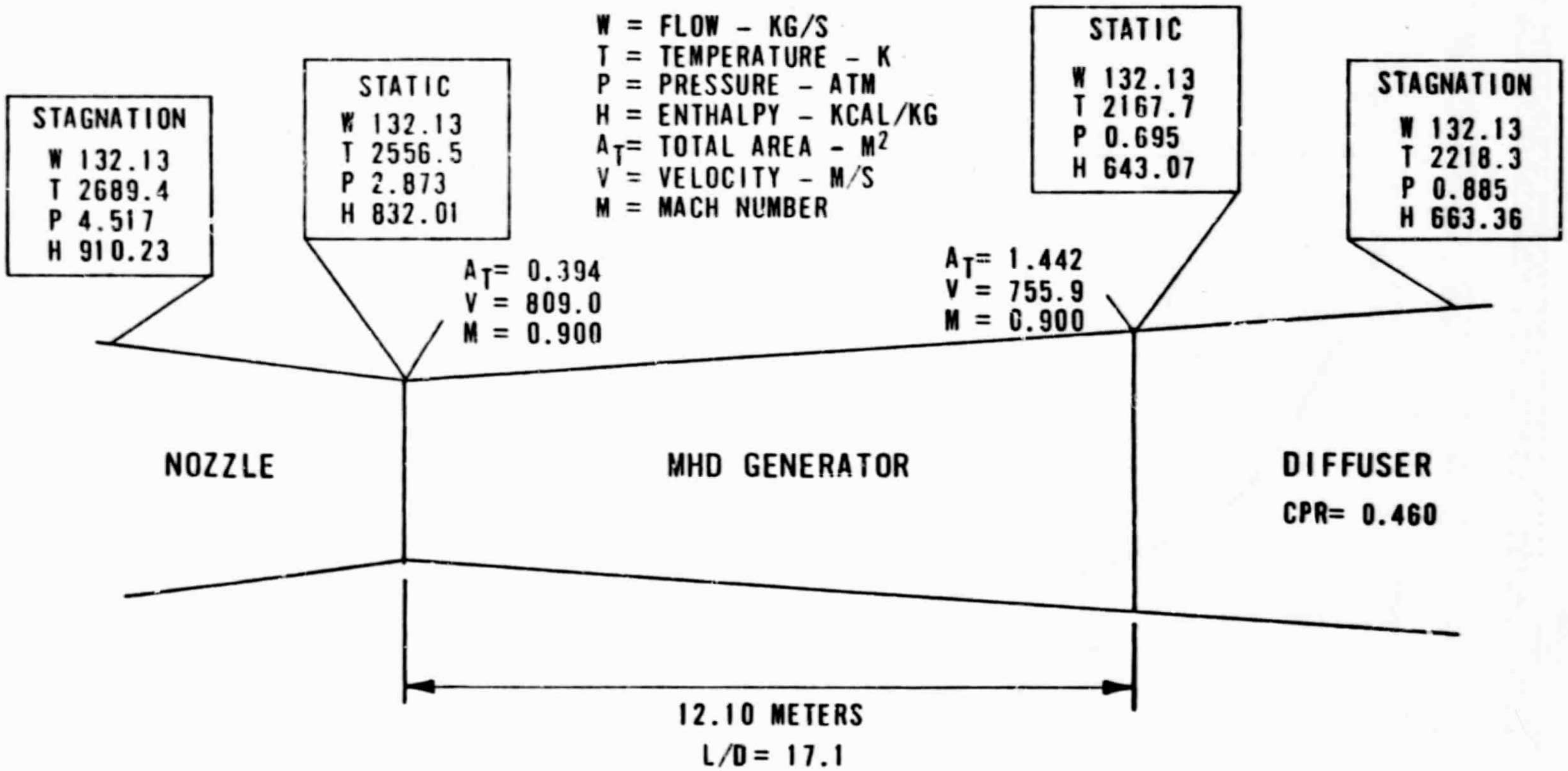


FIGURE 2.5
MHD CHANNEL FOR A 200 MWE POWER PLANT

TABLE 2.5

MHD CHANNEL/PERFORMANCE

		200 MWe Plant Channel Estimate
COMBUSTOR:		
Preheat	°F	1,100
Moles Oxygen in Oxidant	%	30
Stoichiometry	-	0.90
Gas Flow	kg/s	132.1
Coal Input	MWt	532
Discharge Pressure	atm abs	4.52
Discharge Temperature	K	2,689
	°F	4,381
Heat Loss	MWt	24.8
	% coal input	4.67
CHANNEL:		
Length	m	12.1
Constant Mach Number	-	0.90
Inlet Velocity	m/s	809
Discharge Velocity	m/s	776
Inlet Cross Section	m x m	0.63x0.63
Exit Cross Section	m x m	1.21x1.21
L/D, inlet	-	17.0
Gross Power Output	MWe	87.1
Heat Loss	MWt	22.9
Extraction Ratio	-	0.173
Inlet Loading Parameter	-	0.75
Discharge Loading Parameter	-	0.84
Maximum Magnetic Field	tesla	6
Maximum Jy	A/m^2	5,833
Maximum Ex	V/m	2,500
Maximum Ey	V/m	3,623
Maximum Hall Parameter	-	4.08
DIFFUSER:		
Pressure Recovery	-	0.46
Exit Pressure	atm abs	0.88
Exit Temperature	K	2,218
	°F	3,532
Heat Loss	MWt	26.54

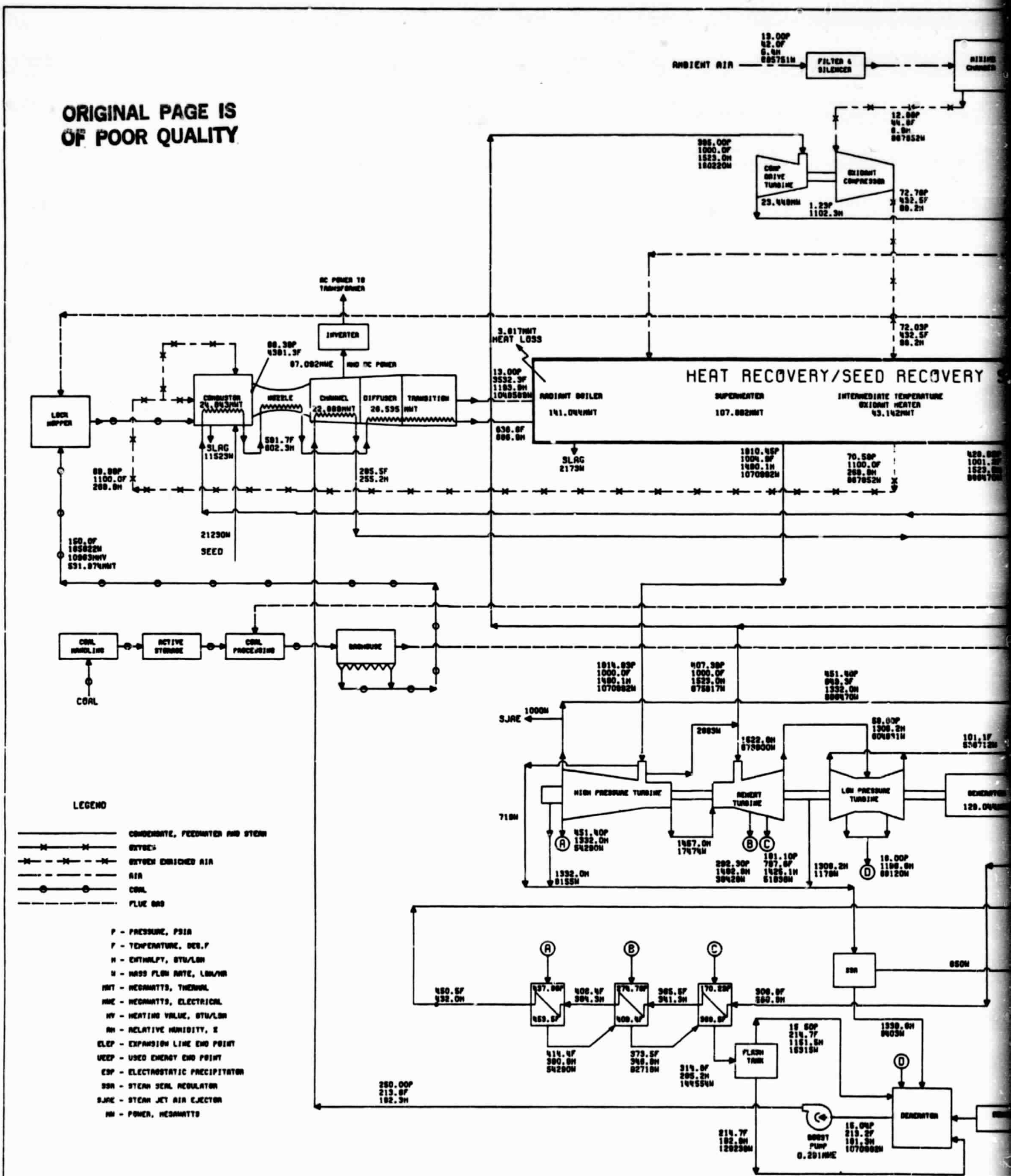
2.6 Heat Recovery and Seed Recovery Components

The hot gases from the diffuser enter the heat recovery boiler (steam generator) with sufficient temperature (3,532°F) and thermal energy to generate steam and to provide the oxidant preheat requirements. The arrangement of the major components for the heat recovery system is illustrated in the system heat and mass balance diagram, Figure 2.6. The components are: the radiant boiler, superheater, oxidant preheater, reheater, and high pressure economizer.

Flue gases exit from the diffuser and enter the water-cooled primary radiant boiler. A portion of the slag is extracted in this furnace. The gas, at reducing conditions, transfers heat to the water-cooled walls, and slowly cools at a rate which allows conversion of NO_x to elemental N_2 and other oxides. This boiler was assumed to have a heat loss of 3.617 MWt, which is 2.5 percent of its total heat transfer.

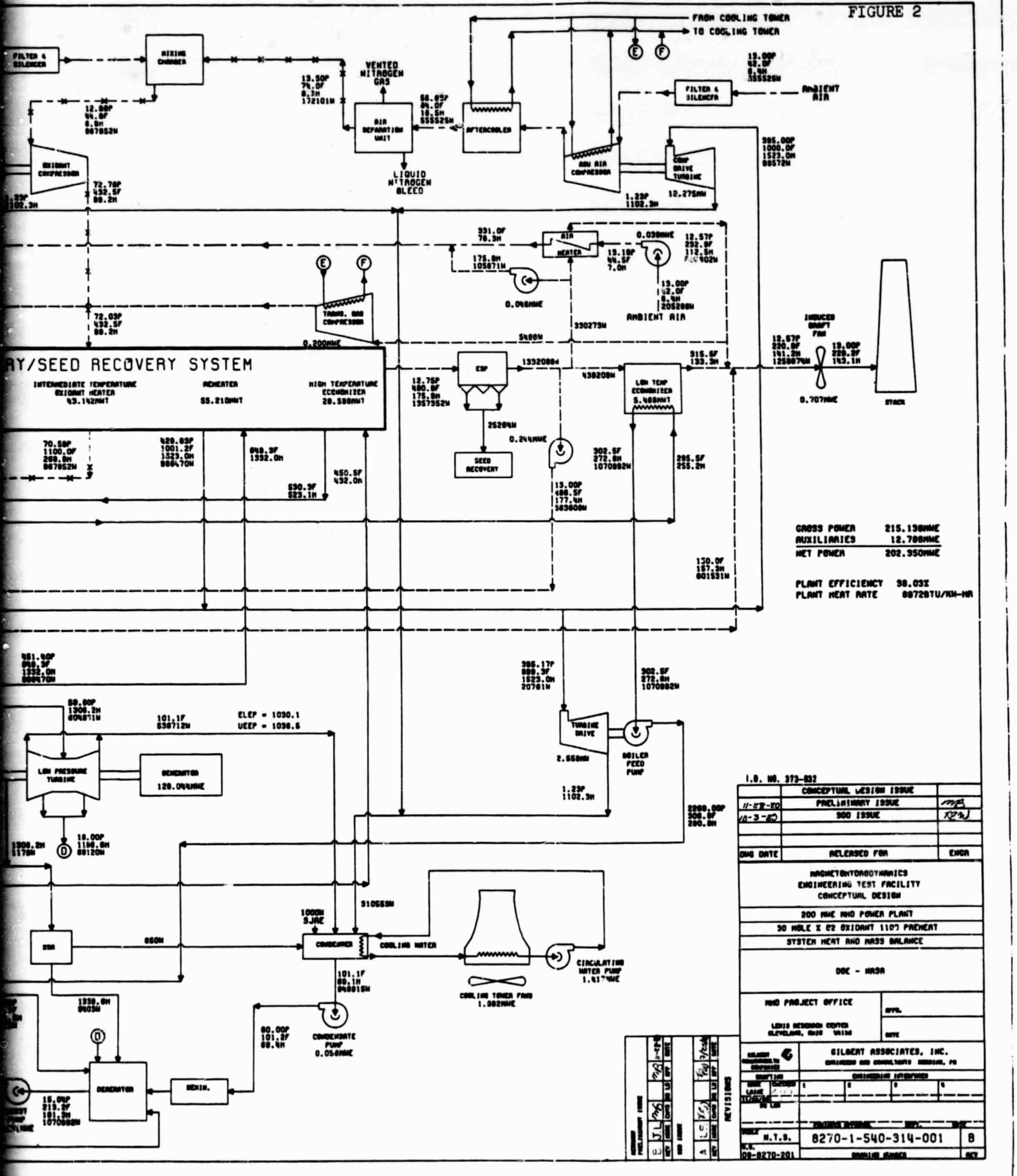
Secondary air, along with recycle gas (used as a temperature control), is injected into the hot gases downstream of the primary radiant furnace to complete the combustion of the MHD exhaust gases. Combustion of carbon monoxide and other species not fully oxidized in the main MHD combustor heats the gas. The flue gas, now at oxidizing conditions, is cooled to 2,400°F with recycle gas.

After passing through the economizer sections, the flue gas enters the gas cleanup system for final seed recovery and particulate removal. This 481°F gas is used for coal drying, for recycle gas, and for low pressure economizing. The gas leaving the low temperature economizer mixes with coal drying return gas and air heater exhaust gas, and discharges to the atmosphere at about 230°F.



FOLDOUT FRAME

FIGURE 2



FOLDOUT FRAME 2

The MHD system is designed to recover the seed material injected into the combustor. A portion of the potassium sulfate recovered in the downstream boiler components may be regenerated offsite to sulfur free potassium salts for reinjection into the combustor. The sulfur in the coal readily combines to form potassium sulfates. In this manner, sulfur removal from the exhaust gases is continuous and, by adjusting the ratio of regenerated seed to potassium sulfate, the EPA sulfur emission limits for the plant will be met.

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SECTION 3

3.0 Steam Bottoming Cycle

3.1 Selection Basis

The steam generated in the waste heat recovery equipment can supply a 125 MWe class steam turbine generator. Steam throttle conditions of 1,815 psia pressure and 1,000°F temperature were selected for this plant. A reheat to 1,000°F was included to improve cycle performance (1.5 points improvement in net plant efficiency compared to a nonreheat configuration).

3.2 Component Sequence

Figure 2.6 illustrates the steam plant flow sequence. Steam condensate is boosted (to a pressure sufficient to overcome line pressure drop), demineralized, and deaerated. From the deaerator the feedwater is further boosted in pressure and circulated through the MHD cannel as coolant. The hot, low pressure feedwater then picks up heat from the MHD exhaust gas in the low pressure economizer of the MHD heat recovery system and is piped to the bottoming cycle for further pressurization in the boiler feed pump. This high pressure feedwater then passes through a string of high pressure regenerative feedwater heaters and is returned to the high pressure economizer of the topping cycle heat recovery system for further heat addition. The feedwater then passes through the MHD combustor, cooling this component, and is converted to steam in the radiant boiler and diffuser using heat from the MHD exhaust gas. The steam is then superheated. The superheated steam is partially expanded in the high pressure section of the turbine and returned to the topping cycle for reheating. After reheat, the steam is split into four flows, one supplying the boiler feed pump drive turbines, the second supplying the ASU air compressor drive turbine, the third supplying the Oxidant compressor drive turbines, and the forth expanding in the low pressure section of the main steam turbine.

3.3 Turbine/Generator

The main steam turbine is a 3,600 rpm, tandem compound, reheat turbine with a double flow low pressure section (TCDF26.0). At full load, the turbine operates at 1,815 psia, 1,000°F design throttle steam conditions. Turbine last stage bucket size (26.0 inches) was selected to minimize exhaust hood loss. The back-end loading for the last stage was 44.4 percent. The used energy end point is at 6.7 percent moisture.

The electric generator is hydrogen cooled and rated for 153,400 kVA at 60 Hz. Its full load output is 128,044 kW.

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SECTION 4

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4.0 System Performance Estimates

The MHD/steam power plant generates 202.3 MWe of net electrical power at the net plant heat rate of 8,972 Btu/kWh (38.0 percent efficiency). Gross electrical output of the MHD generator is 87.1 MWe. The total mechanical power output of the steam turbines totals 168.6 MW, with a total of 35.7 MW produced by the ASU and the Oxidant compressor drive turbines, 2.6 MW by the boiler feed pump drive turbines, and 130.3 MW by the generator drive turbine. Generator mechanical and electrical losses total 2.3 MW, resulting in a gross steam generator electrical output of 128.0 MWe.

Losses must be deducted from gross plant output to account for mechanical auxiliaries, electrical auxiliaries, and generator losses. Mechanical auxiliary loads are 35.7 MW for the steam driven compressor drives, and 2.6 MW for the boiler feed pump drives. Electrical auxiliary loads total 12.8 MWe. Electrical and mechanical losses in the bottoming cycle electrical generator are 2.3 MW, resulting in a total system power loss of 53.4 MW. The estimated performance characteristics are summarized in Table 4.1 and 4.2, and the system heat balance is shown in Figure 2.6.

The design coal flow rate to the MHD combustor is 165,622 lb/hr (532.0 MWt). The coal is burned in the MHD combustor at 90 percent stoichiometery with 1,100°F preheated air enriched to 30 mole percent oxygen. The product gas, seeded with potassium carbonate and potassium sulfate, passes through the MHD generator and diffuser.

In order to keep the coolant water temperature below 300°F in the MHD channel, demineralized and deaerated low pressure feedwater is sent directly to the channel.

TABLE 4.1

SYSTEM PERFORMANCE ESTIMATE

GROSS OUTPUT: MW		
MHD Power		87.1
Steam Mechanical Power		
Turbine Mechanical Power	130.3	
Compressor Drive Power	35.7	
Feed Pump Drive Power	2.6	
	168.6	168.6
LOSSES: MW		
Topping Losses	-6.9	
Compressor Power	-35.7	
Bottoming Losses	-8.2	
Feed Pump Power	-2.6	
	-53.4	-53.4
NET OUTPUT: MWe		
Net Plant Output		202.3
INPUT: MWt		
Coal to Combustor		532.0
NET PLANT PERFORMANCE:		
Efficiency, Percent		38.0
Heat Rate, Btu/kWh		8,972

TABLE 4.2

SYSTEM POWER LOSS SUMMARY

	Kilowatts
Topping Losses:	
Fuel Handling	1,288
MHD Transformer	1,742
MHD Inverter	871
Magnet	139
Seed Regeneration	198
Secondary Air Fan	38
Recirculation Flue Gas Fans	46
Coal Drying Flue Gas Fan	244
Transport Gas Compressor	200
Induced Draft Fan	707
Cleanup System	1,397
Total MHD Losses	6,870
Bottoming Losses:	
Ash Handling	334
Service Water System	60
Steam Turbine	98
Transformer	1,280
Cooling Tower Fans	1,982
Condensate Pump	56
Booster Pump	291
Circulating Water Pump	1,417
Miscellaneous	396
Generator Mechanical	696
Generator Electrical	1,604
Total Steam Plant Losses	8,214

High pressure feedwater is used to cool the MHD combustor and nozzle. The coolant flow rate is 1,070,992 lb/hr. After cooling the nozzle, the feedwater is converted to steam in the radiant furnace and diffuser using heat from the MHD exhaust gas. It is then superheated by the exhaust gas in a convective heater. The design steam turbine throttle flow of 1,070,992 lb/hr is then delivered to the turbine high pressure section at 1,815 psia, 1,000°F. The steam exhaust from the high pressure turbine section is reheated to 1,000°F prior to expansion in the reheat turbine section.

The ASU compressor and Oxidant compressor power 35.7 MW, and the bottoming cycle boiler feed pump power, 2.6 MW, are provided by condensing steam turbine drives with 2.5 inches HgA back pressure. About 30.0 percent of the reheated steam from the main turbine high pressure section is expanded in the compressor drive turbines and 2.1 percent is used in the boiler feed pump drive turbines. The remaining 67.9 percent of the reheat flow expands through the reheat and low pressure turbine sections.

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SECTION 5

5.0 References

1. Gilbert/Commonwealth; Oxygen Enriched Air Production for MHD Power Plants; Reading, Pennsylvania; May 1980.

5.2.2 Pertinent Studies

A number of studies, investigations, and/or document reviews were conducted in the course of developing the CDER in order to provide the detail analyses required for resolution of critical or complex plant requirements. One of these studies, which established the heat and mass balance requirements of the plant, has been included in Section 5.2.1 as the Design Antecedent for this CDER. Another, which supported the design of the MHD Power Train channel, has been included as Appendix C to SDD-502, "MHD Power Train". A number of other studies were also conducted to evaluate possible improvements to plant design cost and/or efficiency. However, it should be understood that results of these studies are not included in the descriptive text of the CDER.

Reports of the results of these studies are included as the following attachments to this section of the CDER:

Subtask Work Order No.	Title
201(3)	Evaluation of Electric Motor Drivers to Replace Steam Turbine Drivers
206(1)	GAI Review of UTSI Topical Report FE-10815-45 - "Evaluation of a Coriolis Mass Flow Meter for Pulverized Coal Flows"
304	On-Site Integration of the RCC Modified Engel-Precht Seed Reprocessing System Into ETF
305	Impact of New Magnetic Field Exclusion for Personnel Access
306(1)	Channel Replacement-Channel Downtime and Its Effects on System Availability
306(2)	Channel Replacement - Arrangement and Evaluation of Alternatives
307	Regenerative Combustor Cooling
308(1)	Operational Costs of the MHD-ETF for the Commercial Phase
308(2)	Pre-Operational Tests of the ETF Topping Side Components

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GAI Ref No. 120-195-201
Engineering Study 201(3)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 201(3)

EVALUATION OF ELECTRIC MOTOR DRIVERS TO REPLACE STEAM TURBINE DRIVERS

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

GILBERT ASSOCIATES, INC.
P.O. BOX 1498
READING, PA 19603

DECEMBER 1980

TITLE: Evaluation of the MHD ETF with Electric Motor Drivers Replacing Steam Turbine Drivers

SCOPE:

An analytical evaluation was made of the effect an all electric motor driver configuration would have on efficiency and cost of the MHD ETF conceptual design.

FINDINGS:

1) Net power output for the all electric motor driver cycle increased 3.9 MWe compared to the steam turbine driver cycle. This increased plant efficiency 0.74 points to 38.76 percent.

2) There would be essentially no increase in ETF cost for the all electric motor driver configuration.

3) The plant arrangement could be simplified by replacing the condensers and steam/condensate piping for the steam turbine drivers by cabling, switchgear, and transformers for the electric motor drivers.

4) Custom design steam turbine drivers are required for the air and oxidant compressors. "Off the shelf" steam turbines using 1000°F steam are not available.

5) The boiler feed pump (BFP) drivers need 1.25 MW class steam turbines. No steam turbine supplier would offer a 1.25 MW unit, either standard or custom design, that uses 1000°F steam. Highest temperature steam for 1.25 MW units was 900°F.

RECOMMENDATIONS:

- The BFP driver design should be revised to incorporate either constant speed electric motors or steam turbines with a lower temperature steam source (e.g. turbine crossover, or primary reheat).

- Constant speed electric motors should be substituted for industrial steam turbines as the drivers for the oxygen plant compressors.

- Details of compressor control mechanisms need to be established to insure that the oxygen plant compressors can be controlled when powered by constant speed drivers.

- The impact of constant speed electric motors on part load heat rate and plant transient response should be determined.

PROCEDURE:

ETF plant performance was analytically evaluated using the GAI PROTEUS computer code. Constant speed electric motor drivers with 98 percent efficiencies (as quoted by General Electric) were substituted for the steam turbines currently employed to drive the air separation unit ASU air compressor, the oxidant compressors and the boiler feed pumps. The reheat and low pressure sections of the main steam turbine generator set were resized to pass the additional steam that was previously used by the turbine drivers.

Costs for the equipment modified for the all electric motor driver configuration were compared with the steam turbine driver configuration to determine impact on plant cost.

DISCUSSION:

The base configuration for the ETF has three steam turbine driver systems that use nearly 32 percent of the hot reheat steam to meet the power requirements of the BFP and ASU air and oxidant compressors. This amount of steam extraction produces a steam flow difference between the high pressure section and the intermediate/low pressure sections of the steam turbine which is not typical in standard power plant main steam turbines. The 128 MWe rating for the turbine generator is also smaller than the steam turbines being ordered for today's power plants. This smaller size and the turbine section flow difference will require a custom designed turbine generator set. The oxygen plant supplier has also indicated that constant speed drivers are adequate to power the ASU air and oxidant compressors. Drivers with variable speed capability to achieve compressor control are not required. The oxygen plant supplier has indicated that compressor flow and pressure control with constant speed drivers can be achieved by employing control techniques such as: variable compressor inlet guide vanes and stators, gas recirculation, throttling, and multiple compressor units. It was then decided to evaluate the MHD ETF cycle with all electric motor drivers to attempt to simplify the steam turbine equipment design requirements and facilitate procurability. The ETF cycle evaluation with all electric motor drivers was conducted at steady state 100 percent load condition. Part load heat rate and plant transient response were not reviewed to determine what impact constant speed electric motor drivers will have on the design.

Figure 1 is a detailed heat and mass balance diagram of the ETF with an all electric motor driver configuration. Figure 2 is the heat and mass balance diagram of the ETF with steam turbine drivers. A comparison of the two diagrams shows the steam flow increase (310, 550 lbm/hr additional) to the reheat turbine. The turbine efficiency for the main steam turbine is over 11 points higher than for the smaller industrial steam turbine drivers, therefore, redistributing the steam to pass entirely through the main steam turbine is a more efficient use of the energy in the steam. In addition, increasing reheat steam flow through the turbine increased the size of the reheat and low pressure sections, improving the overall turbine section efficiency 0.4 points. The more efficient use of the reheat steam flow and the increased steam turbine efficiency combined to increase steam bottoming cycle efficiency 2 points to 41.6 percent and also increased main steam

turbine generator gross power output by 43.6 MWe. Offsetting this gross power output increase is a 39.7 MWe increase in plant auxiliary load, due mainly to the added electric drivers for the BFP and ASU air and oxidant compressors. The net result is a 3.9 MWe increase in net power output compared to the steam turbine driver case. The 3.9 MWe increase improved plant efficiency 0.74 points to 38.76 percent.

The 43.6 MWe increase in gross power for the all electric motor driver cycle increased steam turbine generator rating to 172 MWe. This turbine generator would then fall in the 200 MWe turbine generator class, a level more representative of units built for today's power plant market. The steam flows through the turbine for the all electric motor driver cycle also reflect levels typical of standard design steam turbines. The all electric motor driver cycle would then require a steam turbine generator that is a standard design in a size closer to the range of units being built today. For the steam turbine driver configuration a custom main steam turbine design in a size smaller than being built today would be required. Choosing a standard design steam turbine in a size more typical of today's market has the following advantages compared to a custom design, smaller size steam turbine.

- Improved procurability through standard design selection.
- Demonstrated reliability from similar commercial units already in service.
- Improved utility recognition and familiarity with the steam cycle operation and control.
- Improved manufacturer warranty.

Although there are no compensating disadvantages in selecting a standard design steam turbine over a custom design, the increased class size (200 MWe versus 125 MWe) for the all electric motor drive cycle turbine results in a $2-4 MM increase in turbine generator cost (see Table 1). Some adjustment in total plant rating may also be required to insure that the rating for the standard steam turbine design matches a size for which engineering drawings already exist.

Table 1 compares the costs for the mechanical drivers. The steam turbine costs include the condenser but not the cost of the steam/condensate piping runs to and from the industrial steam turbines. The electric motor costs include the associated switchgear, transformers and busses but not the cost of the additional cabling or cable trays. At the time this study was conducted data was not available that would permit the evaluation of the piping run costs for the steam turbine drivers. It was felt that a detailed evaluation of pipe length, number of valves and elbows to determine piping cost for the turbine drivers was also beyond the scope and level of detail of this study. For the same reasons cabling and cable tray costs for the electric motor drivers were not estimated. GAI feels that although cabling to supply the electric motor drivers and the piping to carry 1000°F steam to the steam turbine drivers are expensive items, their costs would be approximately the same and, therefore, would not influence the overall plant cost. The net

result of the driver cost estimates indicate that the constant speed electric motors cost \$3.2 MM less than the steam turbine drivers. This roughly offsets the \$2-4 MM increase for the larger turbine generator required for the all electric motor driver configuration, producing no increase in overall plant cost when taken in context with the estimated total plant cost of \$600 MM.

Plant arrangement will be simplified by the use of electric motor drivers. The steam/condensate piping runs and condenser systems for the steam turbines drivers will be eliminated. Cabling and cable trays will, however, be needed to accommodate the electric motor drivers. In general, a simpler, neater plant arrangement would result by using all electric motor drivers.

In summary the study has shown the following:

- Improved plant efficiency for the electric motor driver cycle compared to the steam turbine driver cycle.

- Several advantages for the standard design main steam turbine generator of the electric motor driver cycle compared to the custom design main steam turbine generator of steam turbine driver cycle.

- No increase in total plant cost for the electric motor driver cycle compared to the steam turbine driver cycle.

- Elimination of the need for special design industrial steam turbine drivers with the electric motor driver cycle.

- Simpler, neater plant arrangement with the electric motor driver cycle compared to the steam turbine driver cycle.

TABLE 1

COST COMPARISON
ELECTRIC MOTOR VERSUS STEAM TURBINE DRIVERS
(January 1981 Dollars)

Driver Application	Steam[1] Turbines	Electric[2] Motors
Oxidant Compressor (2 50% units)	\$2,402,000	\$ 762,000
ASU Air Compressor (1 100% unit)	\$1,203,000	\$ 381,000
Boiler Feed Pump (2 50% units)	\$ 950,000[3]	\$ 202,000
Subtotal (Drivers)	\$4,550,000	\$1,345,000
Main Turbine Generator	\$11,540,000-\$13,849,000[4,5]	\$15,696,000[4]
Total (Turbine Generator & Drivers)	\$16,090,000-\$18,399,000	\$17,041,000

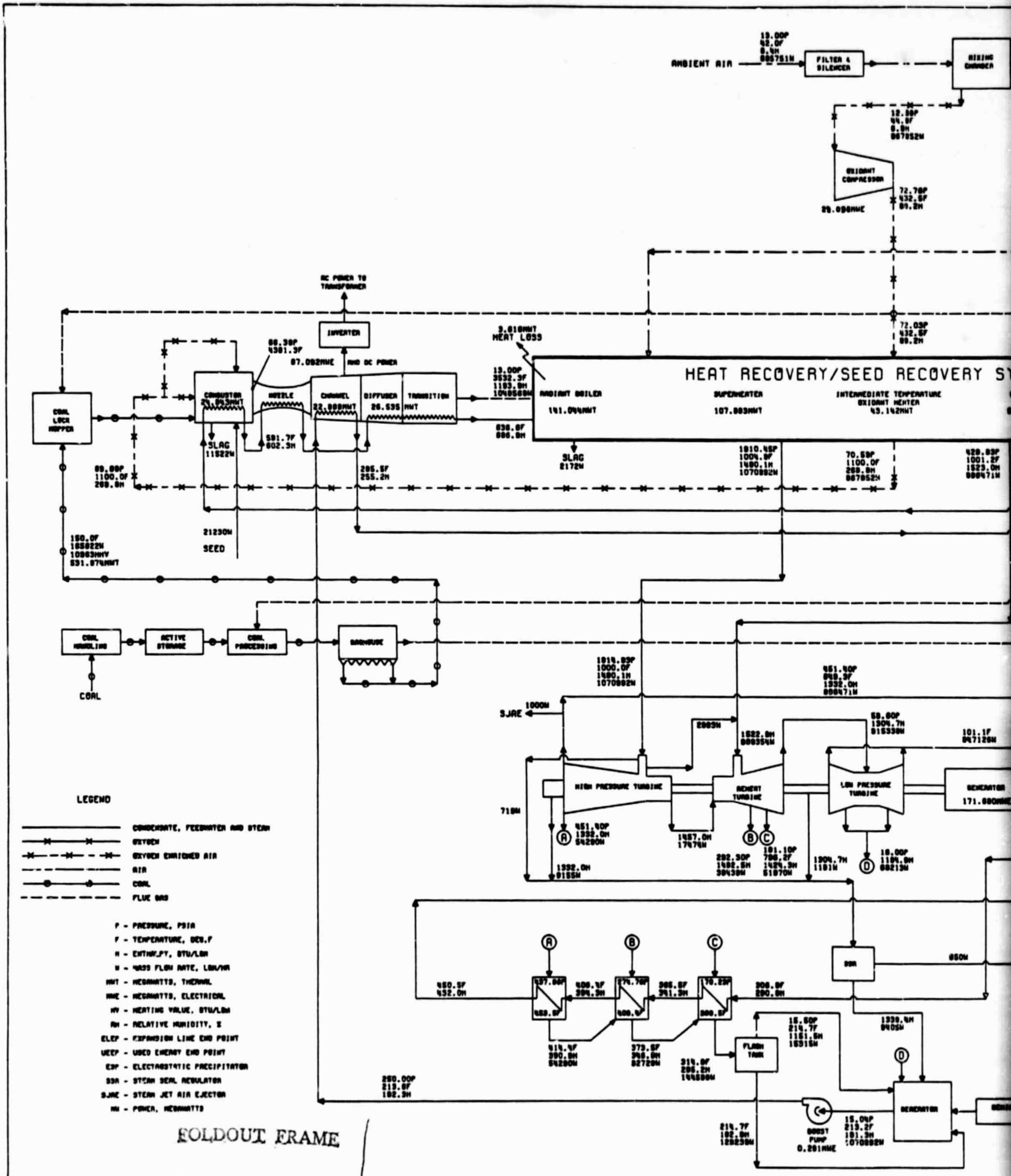
1 Includes condenser

2 Includes switchgear and transformers

3 Cost estimate based on 900°F steam to turbine. Vendors would not supply 1.3 MW steam turbine using 1000°F steam.

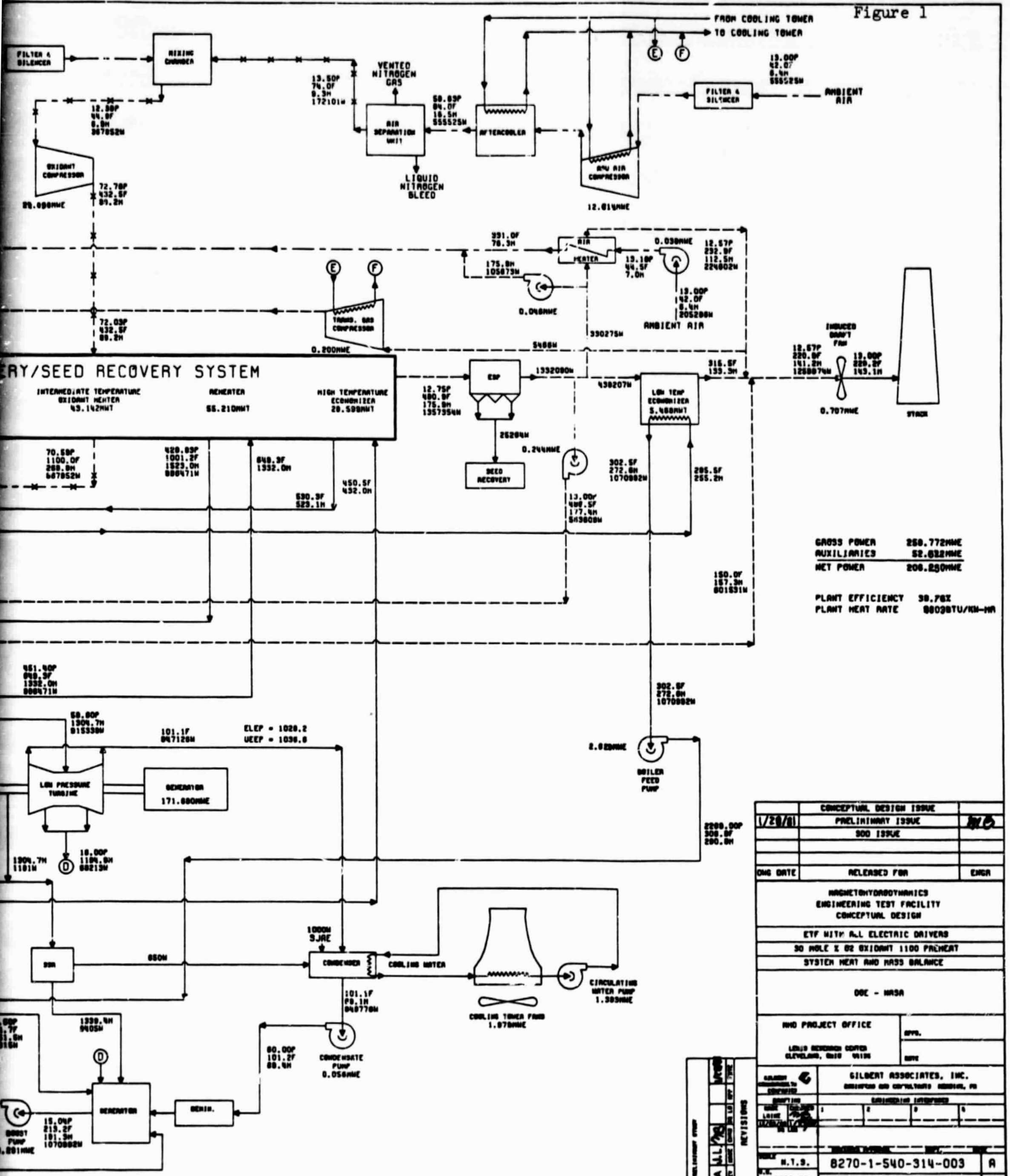
4 Cost based on General Electric price list. Escalated from \$1975 to \$1981 using Equipment Cost Index Factors published in Chemical Engineering, by McGraw-Hill Publications

5 GAI estimated cost range for a custom designed 125 MWe steam turbine generator.



FOLDOUT FRAME

Figure 1



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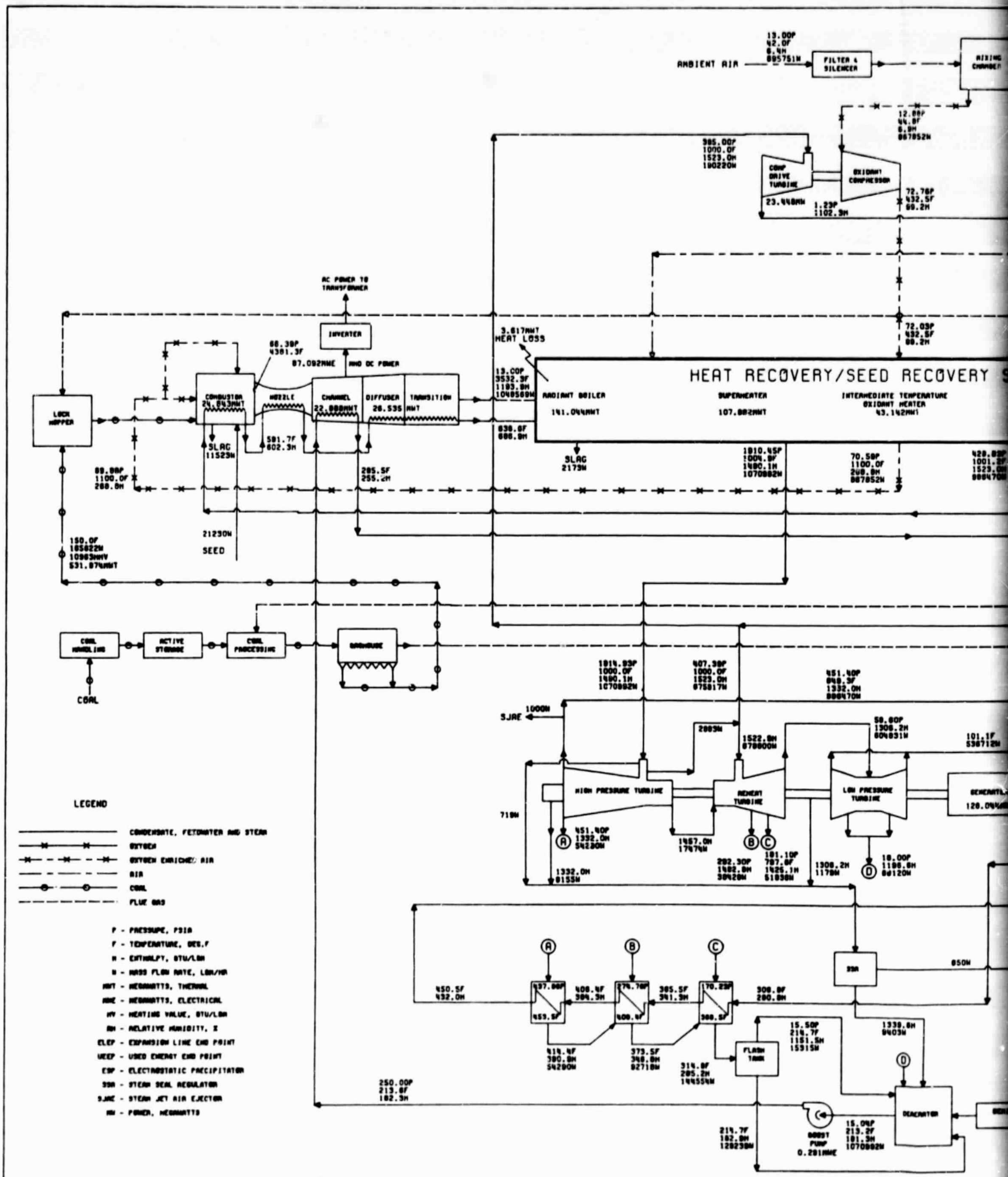

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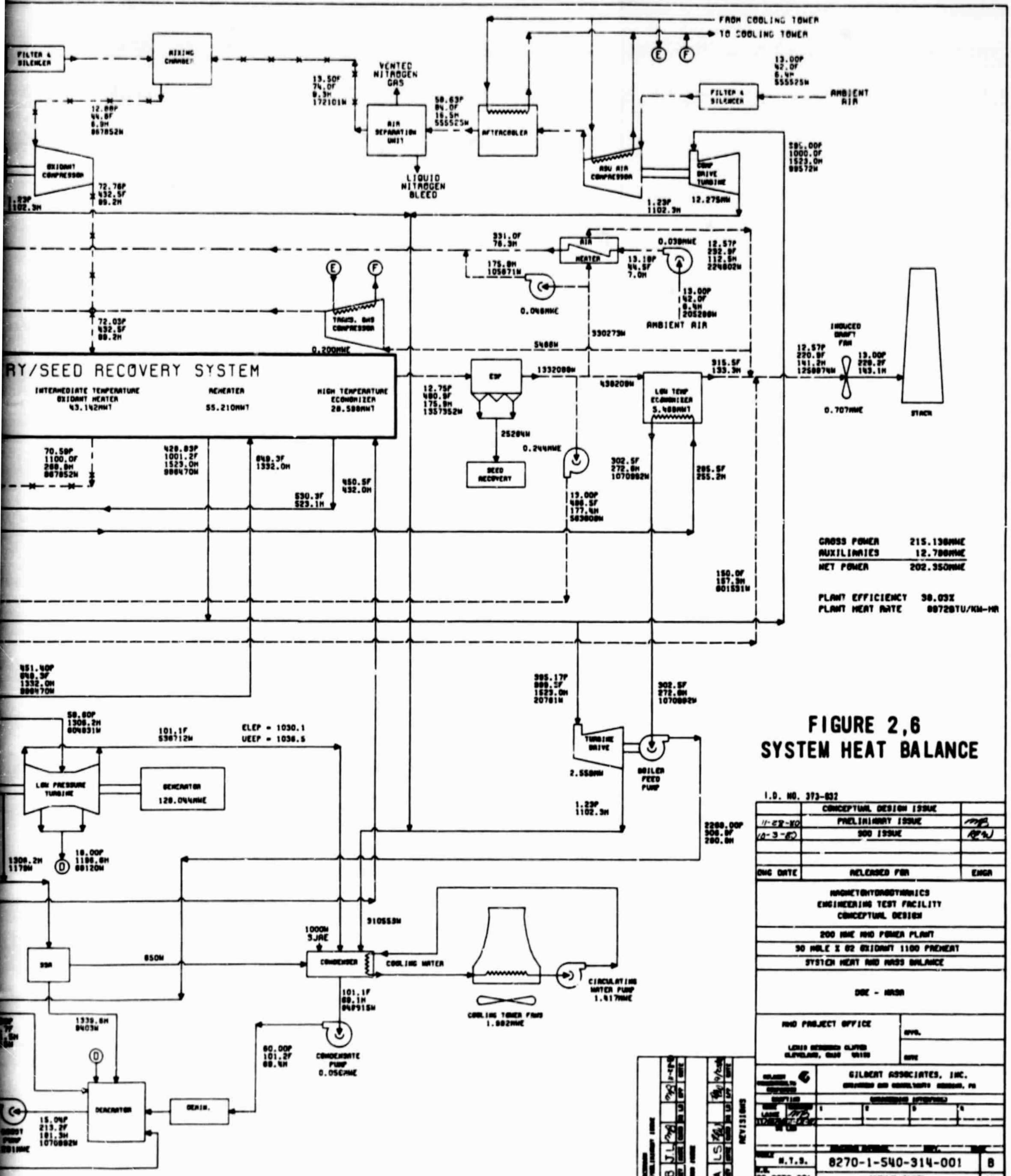

FIGURE 2,6
SYSTEM HEAT BALANCE

FOLDOUT FRAME 2

GAI Ref. No. 110-150-201
ETF DS Review No. 206(1)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ETF DEVELOPMENT SPECIFICATION (DS) REVIEW
SUBTASK WORK ORDER 206(1)

GAI REVIEW OF UTSI TOPICAL REPORT FE-10815-45

"EVALUATION OF A CORIOLIS MASS FLOW METER FOR PULVERIZED COAL FLOWS"

PREPARED FOR:

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY:

GILBERT ASSOCIATES, INC.
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DECEMBER 1980

ABSTRACT

The University of Tennessee Space Institute (UTSI) conducted performance testing on a Micro Motion Coriolis flow meter using pulverized coal in a gas stream as the flow medium. Their evaluation report has been reviewed by Gilbert Associates (GAI) and the reviewers, based on the (UTSI) test results and on corroborating evaluations of similar flow meters by GAI personnel concur in the recommendations that the flow meter has good potential for use in MHD coal and seed injection systems. Areas of concern with regard to gas-particle ratios and vibration effects and probable solutions are discussed and the types of additional testing needed to resolve equipment uncertainties are outlined.

ETF DEVELOPMENT SPECIFICATION REVIEW NO. 206(1)
GAI REVIEW OF UTSI TOPICAL REPORT FE-10815-45
"EVALUATION OF A CORIOLIS MASS FLOW METER
FOR PULVERIZED COAL FLOWS"

TABLE OF CONTENTS

SUMMARY

Coal fired MHD generating systems require continuous monitoring and accurate control of multiphase mass flows of pulverized coal/gas and seed/gas mixtures to the combustion chamber to insure uniformity of the high temperature plasma. As a means of providing that capability the University of Tennessee Space Institute (UTSI) recently tested the Micro Motion Coriolis flow meter by monitoring multiphase flows of pulverized coal and its nitrogen gas carrier. This flow meter showed promise as a practical means for monitoring mass flows directly. The operation of the flow meter is based on imparting a Coriolis acceleration to the fluid flowing through a U-shaped sensor tube within the meter and measuring the angular deflection of the U-tube resulting from the forces acting upon the tube.

The UTSI coal feed system was used to monitor pulverized coal/nitrogen gas mixtures at flow rates varying from 0.45 to 1.34 lbm/sec and with coal/gas mass ratios varying from dense phase coal down to a coal/gas mass ratio of 49:1. Test results showed that the Micro Motion flow meter accurately monitored dense phase coal flow and followed flow fluctuations and minor slugging in the flow with good response, for coal/gas mass ratios down to about 130:1. Below coal/gas mass ratios of 130:1 slugging in the flow became severe and the flow meter behaved erratically with uncorrelated response to flow.

Slugging flow is not desired in MHD coal feed systems and the sensitivity of the Micro Motion flow meter to fluctuations in the flow makes it a promising design aid for determining flow limitations in new MHD coal feed systems as well as a device for adjusting and steadying flows in estalished systems.

The preliminary tests conducted at UTSI indicate good performance potential of the flow meter for MHD application. UTSI was successful in utilizing the Micro Motion flow meter to establish the desired coal flow rate without slugging or other flow oscillations in their MHD coal flow system. However, the flow ranges and conditions considered during testing are not those presently defined for the Engineering Test Facility (ETF), which is to be a 200 megawatt electrical (MWe) net output MHD power plant.

The Micro Motion Coriolis flow meter has proven successful in hundreds of various applications and preliminary assessment by Gilbert Associates (GAI) concurs with the findings of UTSI that the Micro Motion flow meter shows high potential for use in monitoring pulverized coal flows in MHD coal supply systems. GAI also feels that this flow meter looks promising for use in the ETF and recommends that further testing under ETF simulated conditions be conducted.

I OBJECTIVE

The objective of this report was a preliminary assessment of the report "EVALUATION OF A CORIOLIS MASS FLOW METER FOR PULVERIZED COAL FLOWS". The evaluation was performed by the University of Tennessee Space Institute (UTSI) and the assessment is part of the investigation as to the potential value of the mass flow meter for measuring flow rates of transport gas - particulate mediums.

II INTRODUCTION AND BACKGROUND

Coal fired Magnetohydrodynamic (MHD) energy conversion systems require continuous monitoring of the multiphase mass flows of pulverized coal/gas and seed/gas mixtures. Accurate control of the admission rate of these mixtures to the combustion chamber is required to insure uniformity of the high temperature plasma and smooth operation of the MHD generator.

The University of Tennessee Space Institute (UTSI) recently conducted performance testing on the Micro Motion Coriolis flow meter by monitoring pulverized coal flow. The pulverized coal stream consisted of a multiphase mixture of pulverized coal and its nitrogen gas carrier.

The Micro Motion mass flow meter was tested by UTSI because it showed promise as a practical means for continuously monitoring mass flow directly without dependence on the properties of the flowing medium. The purpose of the UTSI investigation was to determine the applicability of this flow meter to an operational MHD power system and to assess the meter's ability to continuously monitor the mass flow of pulverized coal/nitrogen gas mixtures and to identify and correct operational problems.

Principle of Operation

A number of techniques have been developed for measurement of multiphase flows. For coal feeding, a timed measurement of the supply hopper weight or volume has been used to measure the average mass flow in situations where high frequency fluctuations are not critical. For seed, there is no previous operational measurement experience. Most conventional techniques measure a quantity that implies mass rather than measuring the mass directly and none of these techniques has been demonstrated to be applicable to the measurement of coal on a continuous basis.

The principal sensing element of the Micro Motion flow meter is an obstructionless U-shaped tube that is vibrated by an electromagnetic oscillator while the flow passes through it. Each moving particle within the tube is thereby subjected to a Coriolis acceleration. The resulting forces angularly deflect the U-tube by an amount that is inversely proportional to the stiffness of the tube and directly proportional to the mass flow rate within the tube. This angular deflection is measured with an optical detector twice during each cycle of tube oscillation. The output from the optical detector is a pulse that is width modulated proportional to the mass flow rate. An oscillator/counter digitizes the pulse width and a mass flow rate signal is generated for display or control use.

The following reference literature, descriptive of the apparatus is included in the appendix of this report:

- Coriolis/Gyroscopic Flow Meter, reprinted from MECHANICAL ENGINEERING, March 1979.
- Gyroscopic principle key to mass flow meter, reprinted from CANADIAN CONTROLS + INSTRUMENTS, January 1978.

UTSI Coal Feed System

The UTSI coal feed system was designed to deliver pulverized coal to the UTSI MHD Research Facility combustor at adjustable rates between 0.3 and 1.1 lbm/sec. By pressurizing a supply hopper with nitrogen, coal is forced through 3/4" diameter (0.652" I.D.) stainless steel tubing. Near the base of the hopper, nitrogen transport gas can be injected into the tubing to aid in transporting the pulverized coal through the supply tubing. The coal flow rate is controlled by adjusting the hopper pressure (up to 100 psig) and the transport gas pressure (up to 115 psig). Most of the testing was conducted with the Micro Motion flow meter installed in the supply tubing just downstream of the transport gas injection point, thereby measuring multiphase coal/gas mixtures. Tests were also conducted with the flow meter installed upstream of the tranpsort gas injection point where a steady flow of pulverized coal existed.

Calibration of the flow meter for coal/nitrogen gas flows was performed by diverting the desired coal flow to a weighing barrel for two minutes. The coal flow rate obtained from the timed weight change was used to calibrate the average reading of the flow for that same rate.

III TECHNICAL EVALUATION AND REVIEW

Evaluation of UTSI Report and Tests

Before attempting to measure coal flow rates, UTSI adjusted and calibrated the flow meter using water as the flowing medium. Initial adjustment is done by obtaining a stable meter output signal of zero at no flow with the flow tube completely filled with fluid. The meter output was recorded for water flow rates ranging from 0.17 to 1.25 lbm/sec. Results were analyzed and they confirmed the manufacturer's claim that the flow meter does respond linearly to mass flow rate.

The flow meter was calibrated by comparing meter output with load cell measurements of coal hopper weight loss. The supply hopper and coal feed line were vibrated to simulate MHD power generating conditions and load cell measurements of coal hopper weight loss were averaged over 7 second intervals in an effort to eliminate vibration effects from actual weight loss measurements. The flow meter was installed downstream of the nitrogen gas injection point and UTSI test results indicated the flow meter followed the flow fluctuations of the pulverized coal/nitrogen gas

mixtures for high coal to nitrogen gas ratios (where slugging was minor) with good response. Slugging was minor at a coal to gas ratio greater than about 250:1. Testing was continued as the coal to nitrogen gas ratio was decreased. Slugging of the flow became more pronounced and at a coal/gas ratio below 128:1 the flow meter exhibited erratic behavior with uncorrelated response to coal flow. With the aid of the manufacturer this problem was traced to damping of the U-tube oscillation by the slugging flow. Slugging flow is not desired in MHD coal feed systems and in this sense the meter may become valuable as a design aid for new MHD coal supply systems as well as a device for adjusting and steadying flows in established systems.

The flow meter was later installed upstream of the transport gas injection point where a steady flow of coal existed, and observed in two actual MHD power generation experiments. Vibration problems were initially encountered because the meter was not rigidly mounted and the vibration caused a drift in the calibrated zero reading. The problem was corrected with firmer remounting and there was no mention of the problem reoccurring.

GAI personnel have used the Micro Motion flow meter for monitoring flows in a developmental gas fired absorbtion heat pump. The flow system contained a high pressure solution pump which pulsated during operation. The pulsations of the fluid were minor and did not affect the accuracy of the meter. However, some minor piping support changes were made and the stable meter output signal was no longer obtainable. Instability resulted from the presence of external vibrations being transmitted to the meter. The problem was solved by restraining the flanges at the inlet and outlet of the meter flow tube. The ability of the meter to identify vibration interference will be necessary in MHD applications because once the flow meter is installed in an operating MHD system, changes in operating conditions may form new vibration mechanisms that could begin to affect the meter stability. However, based on other operational experiences, as described above, GAI does not feel that vibration will be a major problem in applying the meter to MHD applications. GAI does feel that more operating and additional installation experience is needed.

Subsequent tests with the meter installed downstream of the nitrogen gas injection point again showed that the meter output became completely erratic when the coal/gas ratio decreased below 128:1. For higher coal/gas mass ratios the Micro Motion flow meter indicated the existance of periods of fairly uniform frequency fluctuations in the flow with slugs of coal and nitrogen gas alternately flowing in the coal line. The observable correlation by UTSI indicated that the Micro Motion flow meter has a good frequency response to variation in mass flow for high to moderate coal/gas mixture ratios where slugging flow is not pronounced enough to damp U-tube oscillation.

The flow meter has also been used in recent UTSI research facility coal burning experiments without problems. They have developed a procedure to control coal and nitrogen flow from startup using the flow meter as a monitor. When the approximate desired coal flow rate is established the nitrogen content is adjusted until the flow becomes steady. By monitoring the U-tube oscillation frequency, changes in the pulverized

coal to nitrogen ratio is immediately detected. The flow meter has also been used to confirm established steady fuel flow and monitor fuel flow in the UTSI MHD research facility experiments.

Application to Commercial MHD Systems

The preliminary tests conducted at UTSI are encouraging and they indicate good performance of the flow meter. However, only limited conclusions can be drawn to the applicability of the flow meter to a commercial size system. Test results also indicate to GAI that the UTSI coal feed system is limited in its ability to convey coal/gas mixtures below a ratio of 128:1 without the flow becoming unsteady. The operating conditions and limitations of the UTSI coal feed system were identified during testing of the Micro Motion flow meter.

The major benefit of this flow meter could be its ability to perform two needed functions in a MHD coal feed system:

- Monitoring and control of the true mass flow rate of pulverized coal mixtures with measurements virtually unaffected by the mixture properties. Tests have shown that the manufacturer's claim of true linearity between meter output and mass flow is valid. However, severe slugging will have a detrimental effect on instrument performance.

- Detection and the accurate measurements of flow fluctuations from first appearance of fluctuations up to severe slugging. Even minor flow fluctuations could be detrimental to MHD operation and the ability to quickly detect and control these fluctuations is critical. This ability will permit evaluation of operational conditions when the coal and transport gas are well mixed and is a valuable design aid for evaluating new and existing MHD coal feeding systems and for mapping out system flow range and slugging limits.

  In addition to the meters analog and/or frequency output which is proportional to mass flow rate, the meter is also equipped with an output for determining the time period of the U-tube oscillation. The natural frequency of the U-tube is a function of the pipe geometry and materials and is also related to the density of the fluid within the pipe. Without knowing the actual temperature of the flowing fluid or the temperature distribution of the U-tube itself, one may not obtain an exact correlation between density and the natural frequency of the U-tube. However, as the density of the flowing medium decreases the oscillation frequency will increase. This output could be used to monitor and control any relative density changes and thus the coal to transport gas ratio thereby eliminating potential problems associated with fluctuations in the plasma properties.

Development Requirements

The Engineering Test Facility (ETF) has been conceptually defined as a 200 megawatt electrical (MWe) net output MHD power plant. This size ETF will require a coal input of 47 lbm/sec. The largest size flow meter that Micro Motion currently produces contains a 2" flow tube and has a flow rating of 33 lbm/sec. This is not the meter's maximum rating but is based on a nominal flow rate of water that produces a 10 psi pressure drop. The maximum flow rate of this meter is limited only by the allowable pressure drop up to a flow rate of about 65 lbm/sec. If the resutling pressure drop is higher than described in the ETF coal supply system, two flow meters could be installed in parallel for a coal flow measurement.

Micro Motion specifies the temperature limitation of the medium flowing through the meter as 257°F (125°C). At higher temperatures forced circulation cooling is required to prevent thermal damage to the optical detector system. This limitation is due to the small distance between the U-tube and the optical detector which has a maximum temperature rating of 347°F (175°C). However, Micro Motion also informs GAI that there are several successful installations where higher fluid temperatures are accommodated by piping nitrogen or cooling air through the meter. For direct application to the ETF the following operating conditions as presently defined should be considered for further testing:

- Mixture temperature range: 100 to 400°F
- Pressure conditions: 1 to 10 Atm.
- Coal/gas mass ratio: 10:1 to 350:1
- Seed/gas mass ratio: 10:1 to 350:1
- Coal types: Eastern bituminous and western sub-bituminous*
- Design coal flow rate: 169056 lbm/hr (47 lbm/sec)

The minimum density of the flowing medium required for accurate meter response should also be determined as the flow meter may impose a minimum coal to gas mixture ratio.

The application of the Coriolis Flow Meter to gas-particle flow measurement in MHD systems is promising. Micro Motion has experience in designing electronic laboratory equipment, electromechanical products and weighing instruments. The method that Micro Motion uses to measure tube deflection is based on well accepted engineering principles. Results indicate that they have produced an accurate flow meter with no moving parts to wear. Solid state electronics are used throughout.

The flow meter has proven successful in hundreds of applications and according to the limited UTSI test results the Micro Motion flow meter was successfully used for establishing the desired coal flow rate without slugging or other flow oscillations in their MHD coal supply system.

In addition to the meter's accuracy and linearity, the design simplicity offers many advantage. Completely non-intrusive, there are no moving parts in contact with the flowing medium.

*UTSI did not indicate the type of coal utilized in their tests.

The flow meter provides accurate measurement with wide rangeability. The meter is easily calibrated and simple procedures for respanning and rescaling the flow meter are provided by the manufacturer.

IV RECOMMENDATIONS AND CONCLUSIONS

Preliminary assessment concludes that the Micro Motion flow meter demonstrated the capability of continuous metering of the mass flow of pulverized coal/nitrogen gas mixtures in a MHD supply system. The UTSI test results showed the flow meter followed the flow fluctuations with good response. The flow meter also shows the additional capabilities covered in this report.

GAI recommends that further testing under ETF simulated conditions be conducted where coal/gas and seed/gas flows into a pressurized combustor may be monitored and evaluated. The accuracy, and equally important, the stability of the flow meter during actual coal-fired MHD operation should be assessed. Installation and operational procedure guidelines are needed for application to commercial size MHD generating systems.

At this time the flow meter cost impact on plant economics appears negligible and the potential for improvement of system performance and reliability would warrent a fairly substantial development effort.

Facilities that have ordered the Micro Motion flow meter for use with either a coal slurry or a coal/nitrogen mixture include:
Adelphi University, Garden City, NY; Amoco, Naperville, IL; Pittsburgh Energy Technology Center, Pittsburgh, PA and Texaco, El Monte, CA. It may prove worthwhile to contact these facilities for any operating data that they may have already obtained.

MECHANICAL ENGINEERING

MARCH 1979

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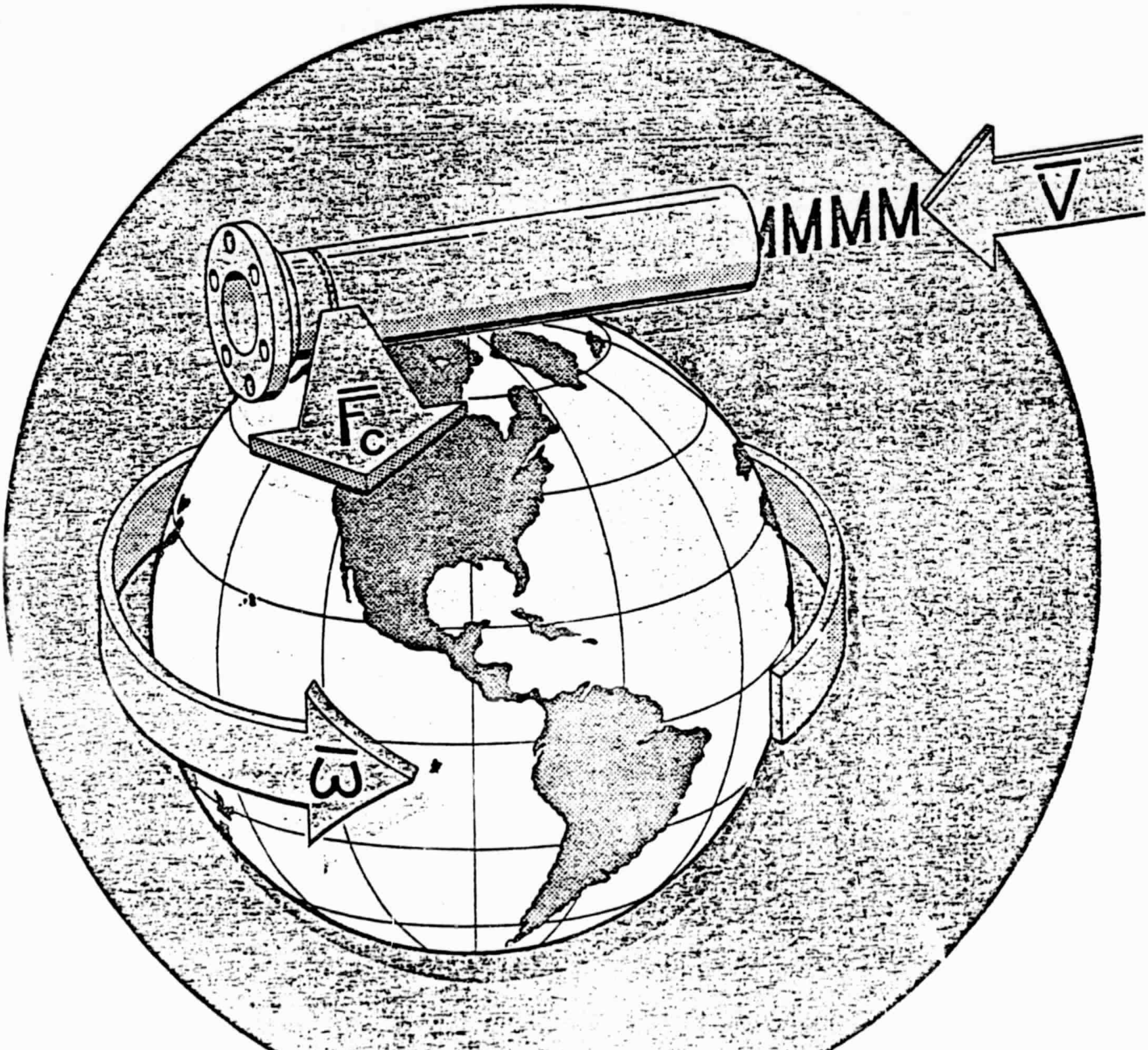

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Coriolis/ Gyroscopic Flow Meter

K. O. PLACHE[1]
Micro Motion, Inc., Boulder, Colo.

Here's a unique mass flow meter that monitors the motion of each molecule of flowing material and sums all of the flow forces to generate a total force that is an accurate, linear measurement of mass flow. The meter, which can be used to measure the flow of gases, liquids, or nonhomogeneous substances, uses electro-optical techniques to sense the forces.

To measure the rate of mass passing through pipe, it is first necessary to fully comprehend how mass itself can be measured. Newton's second law (F=MA) provides the means of measuring mass. The law states that when an unbalanced system of forces acts on a body, it produces an acceleration in the direction of the unbalanced forces that varies inversely and proportionally to the mass of the body. The important concept is that mass cannot be measured without applying a force on the system and then measuring the resulting acceleration.

There are obvious difficulties in measuring the acceleration of a fluid due to a given force. Therefore, most flow meters on the market today measure a quantity that implies mass—instead of measuring that mass directly. One example of an inferred mass flow meter is the thermal type meter which measures the implied mass rate of flow under certain restrictions such as constant specific heat. Another inferred method is by use of a volume-type meter with proper corrections for temperature, specific gravity, and pressure. The mass flow rate is based on a computation using these several parameters.

There is a need to measure mass flow directly, and devices have been developed to accomplish this difficult task. The angular momentum mass flow meter consists of an impeller to impart a swirl to the flowing fluid and a means to measure the amount of torque required to remove the swirl that is generated. The concepts of measuring Coriolis forces and measuring gyroscopic precession have been investigated and development work has been going on for many years. The major problems associated with such meters is the difficulty in measuring the extremely small forces produced.

This article describes a mass flow meter that successfully uses the gyroscopic or Coriolis principle in directly measuring the mass flow rate. It also describes the development of a new and simple method of applying electro-optical techniques to make use of these concepts practical.

The new gyroscopic mass flow meter developed by the author's company employs a C-shaped pipe[2] and a T-shaped leaf-spring as opposite legs of a tuning fork, Fig. 1. An electromagnetic forcer excites the tuning fork, thereby subjecting each moving particle within the pipe to a Coriolis-type acceleration.[3] The resulting forces angularly deflect the C-shaped pipe an amount that is inversely proportional to the stiffness of the pipe and proportional to the mass flow rate within the pipe.

[1] Mem. ASME.
[2] This C-shaped configuration can be recognized as one-half of the loop of the classical gyroscopic mass flow meter.
[3] Coriolis acceleration, due to angular rotation, is described later.

The angular deflection of the pipe is optically measured twice during each cycle of the tuning-fork oscillation. The output of the optical detector is a pulse that is width modulated proportional to the mass flow rate. An oscillator/counter digitizes the pulse width and displays a numerical indication of mass flow rate.

The total mass flow over a given time interval is obtained using a digital integrator to sum the pulses of the flow rate indicator. In this way totalized flow is updated each oscillation of the tuning fork.

This mass flow meter eliminates the many problems associated with mass flow measurement. The output of the meter is directly proportional to mass flow rate; consequently, there is no need to measure the critical parameters of pressure, velocity, temperature, viscosity, or density. There are no parts in the flowing fluid and accuracy of the meter is unaffected by erosion, corrosion, or scale buildup in the flow sensor.

In laboratory tests on prototype units, accuracies in the order of ±0.2 percent FS have been recorded using fluids ranging in specific gravity from 0.5 to 2.5 and in flow rates from 0.1 to 25 lb/min, Fig. 2. The flow meter is linear to within ±0.2 percent FS over the total flow range. Tests have been conducted using both Newtonian and non-Newtonian fluids with a wide range of viscosities; the results indicate the meter is totally insensitive to viscosity. With the meter it is now possible to measure pulsating flow and two-phase flow.

In discussing the concepts for measuring mass flow with a meter based upon the principles of Coriolis force or gyroscopic precession, an explanation of Coriolis force, the force that cause a gyroscope to precess, is in order.

Coriolis force is generally associated with a continuously rotating system. Coriolis force due to the earth's rotation causes winds from a high-pressure area to spiral outward in a clockwise direction in the northern hemisphere and counterclockwise in the southern hemisphere. Depending on location, a projectile fired from a gun in the northern hemisphere will appear to veer slightly to its right, and to the left in the southern hemisphere. Figure 3 illustrates how the effect of Coriolis force can be experienced. A body moving on a rotating frame of reference such as a turntable or a merry-go-round will experience a lateral force and one must lean sideways in order to move forward when walking outward along a radius.

Gyroscopic Precession

Gyroscopic precession is a property of gyroscopes that is exhibited when a torque is applied at right angles to the spin axis. The torque will produce a rotation at right angles both to the spin axis and the applied torque axis. To better understand this, imagine a gyroscope with its flywheel in a vertical plane, spinning about its horizontal axis, and supported at one of its ends. The spinning flywheel is apparently resisting the force of gravity and at the same time it moves around its point of support in the horizontal plane. This movement is called precession.

In essence the Coriolis force and gyroscopic precession are a result of the same principle. Viewed in a simplified manner, Coriolis force involves the radial movement of mass from one point on a rotating body to a second point. As a result of such movement, the pe-

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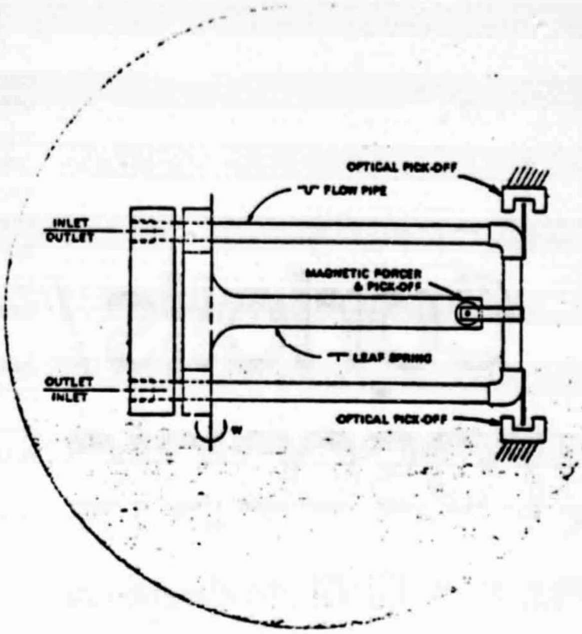
Fig. 1 Mechanical configuration of the inside of the mass flow meter including the U-shaped tube, the electromagnet which vibrates the tube, and the optical pickoffs to detect the amount of twist the mass imparts on the tube.



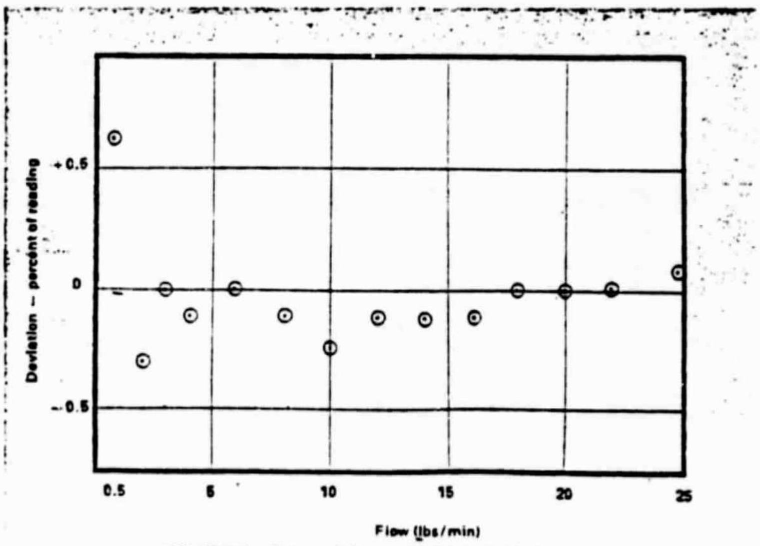
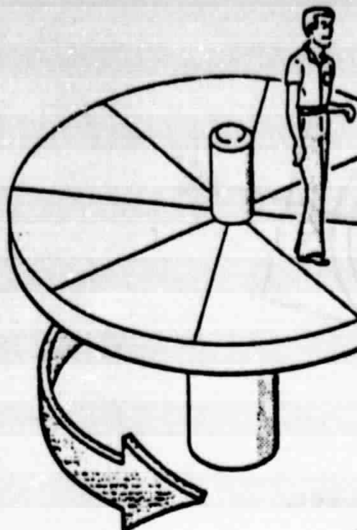


Fig. 2 Laboratory tests using both Newtonian and non-Newtonian liquids with a wide range of viscosities indicate accuracies within ±0.2 percent of full scale readings



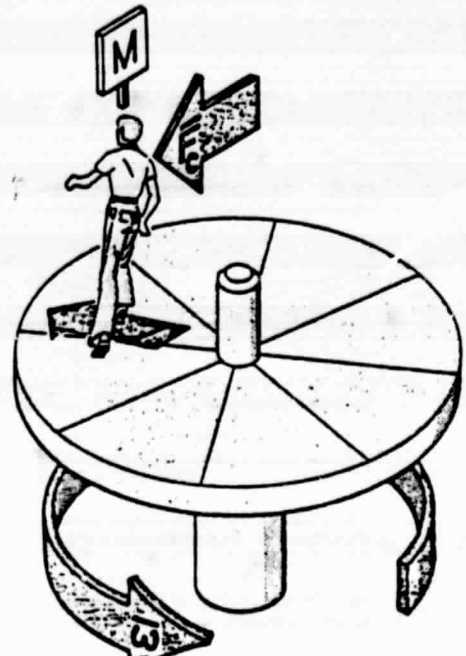


Fig. 3 If a person were standing at the center of a merry-go-round and tried to walk in a straight line toward the edge, he or she would have to lean sideways against the Coriolis force to stay on line. The Coriolis force, $\bar{F}_c$, can be calculated using the mass of the person's body, M, the velocity of travel, $\bar{V}$, toward the edge, and the angular velocity of the merry-go-round, $\bar{\omega}$. $\bar{F}_c = 2M\bar{\omega} \times \bar{V}$.

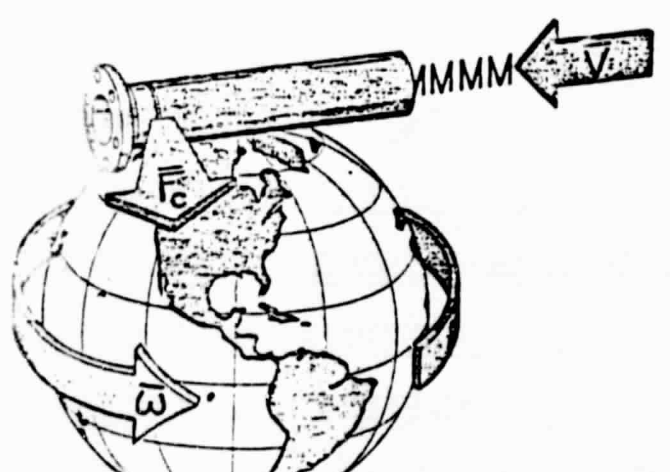


Fig. 4 If a section of pipe is placed on the earth as shown with a mass, M, moving through it at a velocity, $\bar{V}$, the angular velocity, $\bar{\omega}$, of the earth would create a force, $\bar{F}_c$, that would twist the contents of the pipe eastward. Three things are necessary for the Coriolis force $\bar{F}_c$ to appear — a mass, a rotating vehicle, and a motion relative to the vehicle.

ripheral velocity of the mass changes, which means the mass is accelerated. The acceleration of the mass, in turn, generates a force in the plane of rotation and perpendicular to the instantaneous radial movement. Such forces are responsible for precession in gyroscopes.

General Operation

Operation of the Coriolis or gyroscopic mass flow meter is most easily explained by referring to Fig. 4, which depicts a section of pipe located on a revolving earth with a north/south orientation. As a mass travels longitudinally through the pipe with a velocity V, a Coriolis force F is present that tends to rotate the pipe about an axis that is parallel to the axis of the earth's rotation. The magnitude of this force F is extremely small and can be calculated as follows:

$$\bar{F} = 2M\bar{\omega} X \bar{V} \quad (1)$$

where: M is the mass of the fluid in the pipe; $\bar{\omega}$ is the angular velocity of the earth; $\bar{V}$ is the velocity of the fluid in the pipe; and X is the vector cross product operation.

In Eq. 1, it should be noted that the angular velocity term ω is not restricted to the domain of constant angular velocity. The Coriolis force is also present if the platform angularly oscillates with a peak angular velocity ω_p. The associated Coriolis force F_p is now an oscillatory force, but nevertheless, it is a force with a peak value proportional to the mass and its velocity.

The sketch in Fig. 5 is of the C-shaped pipe and shows both the axis of oscillation (ω) and a unit length of fluid within each leg of the pipe.

It is seen that the velocity vectors V_1 and V_2 are perpendicular to the angular-rotation vector (ω), and that the Coriolis force vectors f_{c1} and f_{c2} are opposite in direction since the velocity vectors, V_1 and V_2, are in opposite directions. When the flow meter is in operation, the angular velocity (ω) is a sinusoidal function, as with any tuning fork, and the forces f_{c1} and f_{c2} are therefore sinusoidal and 180 deg out of phase with each other. Forces f_{c1} and f_{c2} create an oscillating moment, M_1 about axis 0, as illustrated in Fig. 5. The moment can be expressed as a force times a distance.

$$\Delta M = f_{c1}r_1 + f_{c2}r_2 \quad (2)$$

If we assume a symmetrical geometry, the two terms are the same, and:

$$\Delta M = 2f_{c1}r_1 \doteq 4M_1V_1\omega r_1 \quad (3)$$

by substituting for f_c from Eq. 1. If the units of M_1V_1 are examined:

$$M \frac{\text{Lb Mass}}{\text{Unit Length}} V \frac{\text{Unit Length}}{\text{Sec}}$$

$$= \frac{\text{Lb Mass}}{\text{Sec}} = \Delta Q$$

where ΔQ is the incremental mass flow rate. Thus Eq. 3 becomes:

$$\Delta M = 4\omega r \Delta Q \quad (4)$$

The total moment, M, about axis 0 due to Coriolis acceleration on all moving particles is given by:

$$M = \int \Delta M = \int 4\omega r \Delta Q = 4\omega r 1 Q \qquad (5)$$

where Q is the mass flow rate in the C-shaped pipe.

The moment, M, due to Coriolis acceleration causes an angular deflection of the C-shaped pipe about the central axis. This angular deflection can be examined using an end view of the C-shaped pipe, Fig. 6, which shows the resultant twist-type motion.

The deflection angle θ due to the moment M is determined by the spring constant of the C-shaped pipe system. This spring constant is a function of the cantilever stiffness of each longitudinal pipe and also the torsional stiffness of each longitudinal pipe. For any given pipe system:

$$\text{Torque} = K_s\theta \qquad (6)$$

where θ is the pipe-system deflection angle and K_s is the pipe system angular spring constant.

Using this equation, one can relate the mass flow rate, Q, to the pipe deflection angle as follows:

$$Q = \frac{K_s\theta}{4\omega r} \qquad (7)$$

Thus, the mass flow rate, Q, is directly proportional to the deflection angle, θ, and inversely proportional to the angular velocity, ω, of the C-shaped pipe system. In considering the optical pickoff system, Fig. 7, one can express Q as a function of Δt, the time interval between optical pulses. The excursion of the C-pipe can be expressed as its velocity times the time interval, Δt, between photo-pulses p_1 and p_2.

$$Vp\Delta t = 2r\theta \text{ or } \Delta t = \frac{2r\theta}{Vp} \qquad (8)$$

where Vp is the velocity of pipe at the position of optical pickoffs and Δt is the time interval that photo pickoff P_1 leads or lags P_2.

Vp, the vertical velocity of the end of the C-pipe, depends on the angular velocity, ω.

$$Vp = L\omega \qquad (9)$$

where L is the length of the C-shaped pipe.

By combining Eqs. 8 and 9,

$$\theta = \frac{L\omega\Delta t}{2r} \qquad (10)$$

and by combining Eqs. 7 and 10,

$$Q = \frac{KsL\omega\Delta t}{8\,r^2\omega} = \frac{KsL}{8r^2}\,\Delta t \qquad (11)$$

The mass flow rate is seen to be a function of pipe geometry constants and Δt, the time interval between photo-pulses. It can also be shown that, if the pipe has a zero-flow deflection angle θ_0, this error is easily removed by comparing the time interval Δt_1 of the downward pipe movement with time interval Δt_2 of the upward pipe movement. If a "no-flow" condition exists, these time intervals subtract out, whereas a fluid flowing in the pipe causes different time intervals (depending on the direction of angular travel) that are detected as flow-induced pipe moments.

An important feature of the optical detection system is that deflection-angle measurements are made near the center position of the C-pipe travel. This is important because this is the time when the velocity and the deflection angle are the greatest. Also, this center

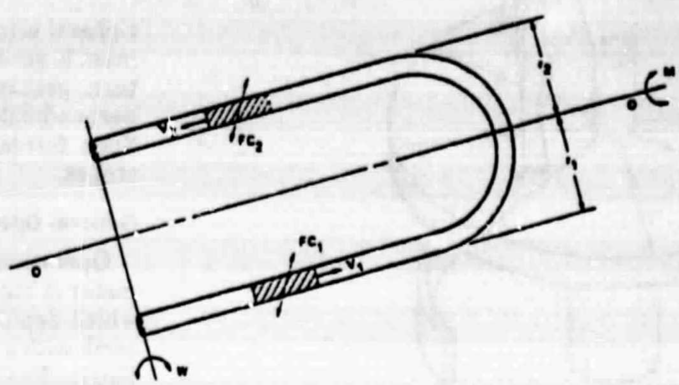


Fig. 5 In operation, the mass flow meter forces, f_{c_1} and f_{c_2}, create an oscillating moment, M, about axis, O.

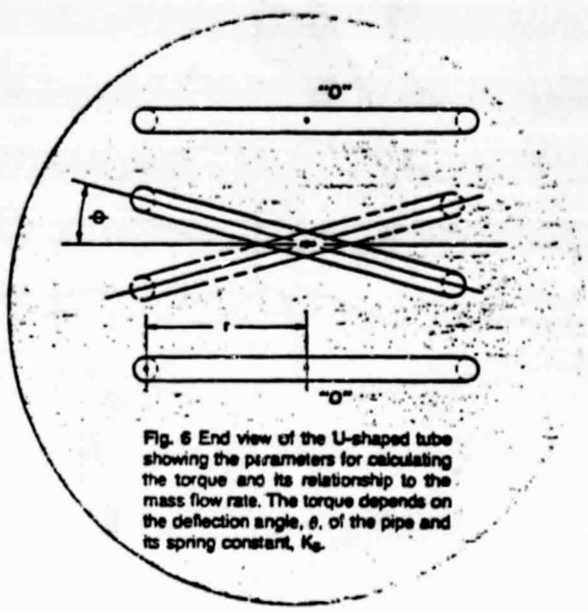


Fig. 6 End view of the U-shaped tube showing the parameters for calculating the torque and its relationship to the mass flow rate. The torque depends on the deflection angle, θ, of the pipe and its spring constant, K_s.

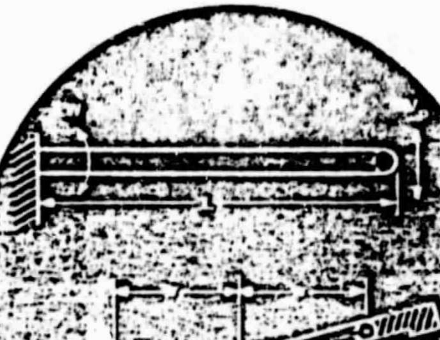


Fig. 7 The excursion of the C-pipe can be expressed as its velocity times the time interval Δt between photo-pulses p_1 and p_2.

position of the C-pipe is the position where the angular acceleration of the pipe is near zero, and any unbalance between pipes is least likely to cause an angular deflection that could be interpreted as a flow signal.

Mechanical Configuration

The mechanical configuration of the gyroscopic mass flow meter is shown in Fig. 1.

The T-shaped leaf spring is clamped or welded to the stationary inlet/outlet end of the C-shaped flow pipe. A magnetic sensor/forcer coil is mounted on the leg of the leaf spring. A permanent magnet, suspended from the center of the C-shaped pipe, passes through the middle of the sensor/force coil. In operation, the velocity of the leaf spring relative to the C-pipe generates a voltage in the sensor coil that is amplified and used to drive the concentric force coil. The force-coil amplifier is gain-controlled using a peak-detector circuit that compares the peak-velocity signal from the sensor coil with a reference voltage, Fig. 8.

Mass Flow Rate Logic

Figure 9 illustrates a slightly warped "C" pipe with two photo pickoffs and some circuitry.

Photo Pickoff Logic Circuit

Figure 10 is a timing diagram illustrating the photo pickoff wave forms P_1 and P_2 and also the flip-flop wave forms f_1 and f_2 for both a flow and a no-flow condition of the unit.

Mass Flow Meter Timing Diagram

On the timing diagram, Fig. 10, the continuous vertical lines represent time intervals where photo pickoffs P_1 and P_2 would switch if the deflection angle θ of the "C" pipe was equal to zero. In the first sequence, that of no flow, photo sensor P_1 switches prior to the vertical time reference on the downward pipe stroke because of a constant deflection angle θ_0 in either the photo sensor alignment or "C" pipe warp angle. On the upward stroke, photo sensor P_1 switches late with respect to the time reference for the same reason. Photo sensor P_2 switches late on the downward stroke of the "C"-shaped pipe and early on the upward stroke because of the no-flow angle θ_0. If one sets and resets flip-flop f_1 with the up-going edges of photo sensor P_1 and P_2, the waveform shown is easily derived. Similarly, flip-flop f_2 is set and reset with the up-going edges of the inverted photo sensor signals P_1 and P_2. As illustrated on the timing diagram, the positive area of waveforms f_1 and f_2 are equal, and if we use these signals to gate an oscillator into an up-down counter, the net count will be zero following each pair of oscillator bursts.

If the same waveforms are now examined for a flow condition, the following situation is found to exist: Photo sensor P_1 switches even earlier due to a counterclockwise Coriolis torque on the down stroke of the "C" pipe and P_1 switches slightly earlier on the up stroke due to a clockwise Coriolis torque on the "c" pipe. The same Coriolis torque causes photo sensor P_2 to switch a little later on the down stroke and slightly later on the up stroke. The waveforms of flip-flops f_1 and f_2 are modified due to the flow forces, and as illustrated in the lower portion of Fig. 10, the positive area of flip-flop f_1 is now much larger than that of f_2 and, hence, the up-down counter will display a positive count that is proportional to the difference in pulse widths of the two flip-flops. As is obvious, the number accumulated in the up-down counter after a given number of "C" pipe cycles will be directly proportional to the time interval, Δt, and, therefore, directly proportional to the mass flow rate in the "C" pipe. This number is not dependent upon pipe oscillation frequency or amplitude; it is not dependent upon cross-sectional area of the pipe; it is only a function of pipe geometry, spring stiffness, and mass flow rate Q, as seen in Eq. 11.

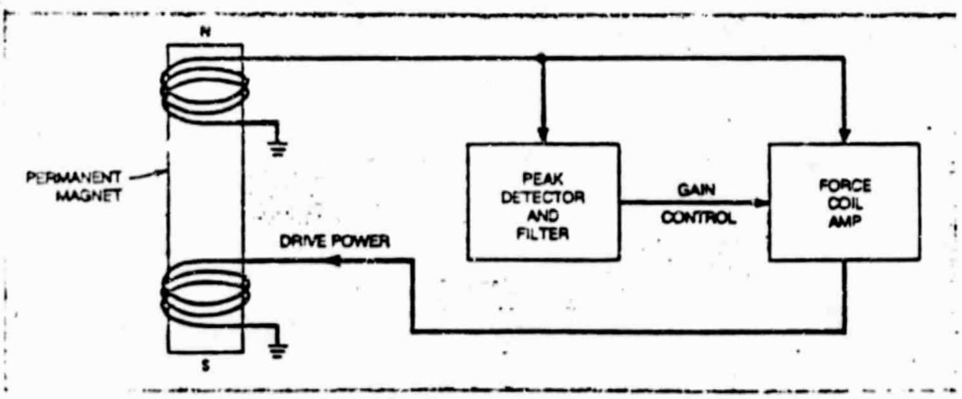


Fig. 8 Block diagram of sensor circuitry.

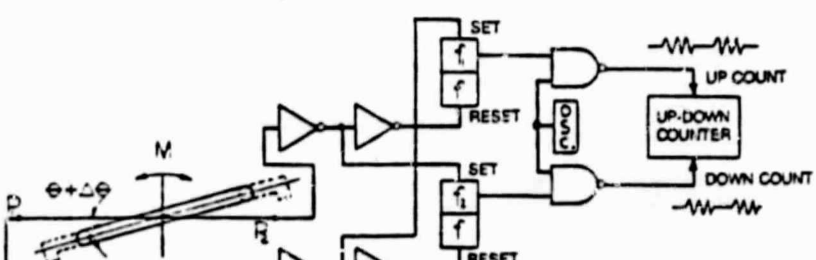


Fig. 9 Mass flowrate meter logic circuit.

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Flow Totalizer Circuit

The total mass flow between time t_1 and t_2 is given by the equation:

$$\text{Total flow} = \int_{t_2}^{t_1} Q d_t \quad (12)$$

where Q is the mass flow rate during the time interval d_t.

If one examines the lower portion of the timing diagram of Fig. 10 it is easy to see that the above integration can be performed digitally if we take the up count pulses from the first burst of flip-flop f_1, and subtract those pulses from the first burst of flip-flop f_2, and then multiply this difference by the d_t time interval that represents one total pipe oscillation cycle. Since the time interval of one "C" pipe cycle is the inverse of the pipe frequency, it is an easy matter to simply divide the pulse difference by the pipe frequency and then continuously accumulate the quotient in a resetable counter that then provides a real time display of the totalized flow following any preset zero reference time.

Density Measurement

The natural frequency of the "C-T" tuning fork (a function of the pipe geometry and materials) is also related to the density of the material within the pipe. Thus, for a given pipe geometry and material, the specific gravity (density) of the fluid within the pipe may be determined by measuring the natural frequency of the tuning fork.

The pipe and leaf spring oscillate 180 deg out of phase with each other in the same manner as the times of a tuning fork oscillate and, as in the case of the tuning fork, little or no vibration is coupled into the base. The frequency of oscillation is determined by the natural frequency of the pipe/leaf spring; the amplitude is controlled by the peak detector circuit.

The period of oscillation of a spring mass/system is given by:

$$\tau = \sqrt{2\pi \, M/ko} \quad (13)$$

where τ is the period of oscillation, M is the mass of the system being oscillated, and ko is the system spring contant.

In the case of the pipe/leaf spring tuning fork of the gyroscopic/Coriolis flow meter, the mass being oscillated can be divided into two parts: the mass of the pipe, Mp, and the mass of the fluid in the pipe, Mf. In this case the period of oscillation is:

$$\tau_1 = \sqrt{k_1 \, Mp + Mf} \quad (14)$$

where τ_1 is the period of oscillation of pipe/leaf spring and:

$$k_1 = \sqrt{2\pi/ko} \quad (15)$$

Since the mass of the fluid, Mf, is equal to the volume multiplied by the mass density, one can restate Eq. 14 as:

$$\tau = k_1 \sqrt{k_2 + k_3 Dfm} \quad (16)$$

where k_1, k_2, k_3 are all fixed constants, defined by the geometry of the flowmeter; and Dfm is the density of the fluid in the "C" pipe.

Conclusion

The Coriolis/gyroscopic mass flow meter can be used to measure the flow of gases, liquids, or nonhomogeneous substances. It is insensitive to temperature and pressure and can be constructed using a variety of materials to provide the necessary corrosion resistance. The unit provides a solution to the problems associated with the mass flow measurement of multiphase flow and cryogenic mass flow.

Based on a paper contributed by the ASME Research Committee on Fluid Meters.

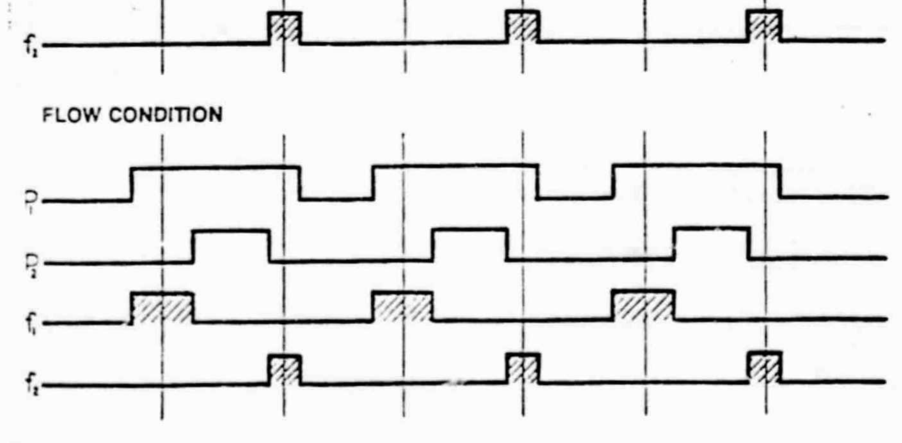

Fig. 10 Timing diagram showing the photo pick-off wave forms p_1 and p_2 and the flip-flop wave forms f_1 and f_2 in both the flow (bottom diagram) and no-flow (top diagram) conditions. The photo pick-offs are staggered so that the system can easily detect subtle changes in mass flow rate. Under no-flow conditions, the areas under the wave forms f_1 and f_2 are equal and the area under p_1 and p_2 are unequal. Under flow conditions, the flip-flops f_1 and f_2 show a discrepancy in areas and the up-and-down counter will display a count proportional to the difference in their pulse widths. The accumulated number in the up-down counter after a given number of pipe cycles will be proportional to the time interval and the mass flow rate in the pipe.

C-2

FLOWMETER WITH A 'NEW' TWIST

Gyroscopic principle key to mass flowmeter

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FLOWMETER WITH A 'NEW' TWIST

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Gyroscopic principle key to mass flowmeter

Hurricane forces could be translated into mass flow data, if the parameters were sufficiently controlled for analysis. On a much smaller scale, this idea yields a novel approach to measuring lower-volume flows . . .

by Murray D. Willer, President Willer Engineering Ltd., Toronto

Murray D. Willer is president of Willer Engineering Ltd., Toronto and is currently vice-president, District 13, of the Instrument Society of America. He is also a member of IEEE. After graduating, in mechanical Engineering (U of T, 1935) he held a number of senior administrative and executive posts with several Canadian aircraft companies, notably National Steel Car, Victory Aircraft and A. V. Roe.

The gyroscopic effect, long used in navigational instruments is now being applied to the industrial field in a mass flowmeter developed by Micro Motion Inc., of Boulder, Colo.

Its origin can be traced to Gaspard Coriolis, who, in 1835 demonstrated that on a rotating surface, there is an inertial force acting on a body at right angles to its direction of motion, in addition to the ordinary effects of motion of the body. This became known as the Coriolis force.

On the Earth, which rotates eastward, an object that moves along a north-south path, or longitudinal line, will attempt to undergo deflection to the right in the Northern hemisphere and to the left in the Southern hemisphere.

The Coriolis force on Earth determines the general wind directions and is responsible for the rotation of hurricanes and tornadoes. The flight path of aircraft and rockets, and the orbiting of space vehicles must also be compensated for the Coriolis effect. Another example is that force which causes a gyroscope to precess when angular inputs are applied to axes other than the spin axis. In essence the Coriolis force and precession in a gyroscope are a result of the same principle.

An excited fork . . .

The mass flowmeter developed by Micro Motion Inc. uses this Coriolis or gyroscopic principle for measuring mass flow directly.

This instrument employs a C-shaped flow tube and a T-shaped leaf spring as opposite legs of a tuning fork. The C-shaped configuration can be considered as one half of the loop of the classical gyroscopic mass flowmeter.

An electro magnetic coil or forcer excites the tuning fork thus subjecting each particle in the flow tube to a Coriolis type acceleration. The resulting forces angularly deflect the C-shaped flow tube an amount inversely proportional to the stiffness of the pipe, and proportional to the mass flow rate within the flow tube.

Optical detectors measure the angular deflection of the flow tube during each cycle of the tuning fork oscillation. The output of the optical detector is a pulse-width modulated signal proportional to the mass flow rate.

Since the output of the meter is directly proportional to mass flow, there is no need to measure the critical parameters of velocity, temperature, viscosity or density.

The meter can be used to measure two-phase flow and can also handle Newtonian and non-Newtonian liquids with a wide range of viscosities.

. . . and a precise tune

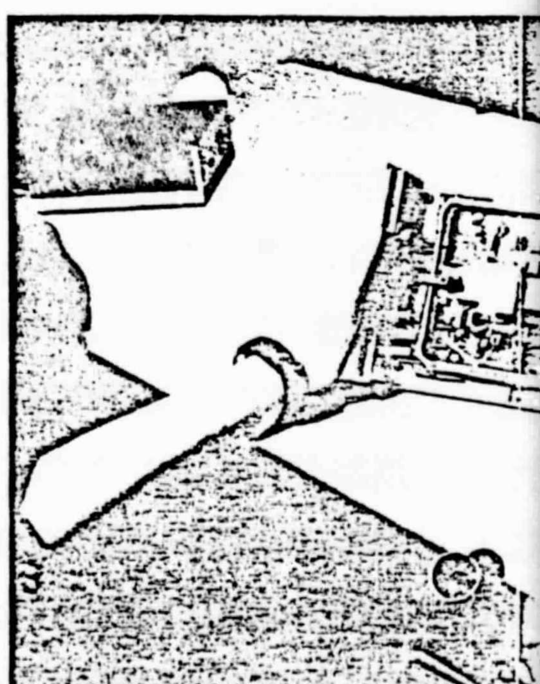
The natural frequency of the tuning fork (flow-pipe/leaf-spring combination) is related to the density of the fluid within the flow tube. For a specific pipe geometry and material, the specific gravity (density) of the fluid within the pipe may be determined from the natural frequency of the tuning fork.

An oscillator/counter digitizes the pulse-width signal and displays the mass flow rate in lb/min. The total mass flow in pounds over a given time is obtained using an integrator to sum the pulses of the flow rate indicator.

The display (which is in a separate enclosure) has three readouts for mass flow rate, totalized mass flow, and specific gravity.

Accuracies in lab tests are about ±.2% fs with fluids in the specific gravity range of 0.5 to 2.5 and flow range from 0.2 to 25 lb/min. Linearity is within ±0.2% fs over the flow range.

The mathematics and other grey areas are provided by James E. Smith of Micro Motion Inc. below.



Gyroscopic/Coriolis Mass Flow Meter

by James E. Smith, Micro Motion, Inc.

The Gyroscopic Mass Flow Meter employs a C-shaped pipe and a T-shaped leaf-spring as opposite legs of a tuning fork (Fig. 2). An electromagnetic forcer excites the tuning fork, thereby subjecting each moving particle within the pipe to a Coriolis-type acceleration. The resulting forces angularly deflect the C-shaped pipe an amount that is inversely proportional to the stiffness of the pipe and proportional to the mass flow rate within the pipe.

The angular deflection of the pipe is optically measured twice during each cycle of the tuning-fork oscillation. The output of the optical detector is a pulse that is width modulated proportional to the mass flow rate. An oscillator/counter digitizes the pulse width and displays a numerical indication of mass flow rate.

The natural frequency of the C-T tuning-fork (a function of the pipe geometry and material) is related to the density of the material within the pipe. Thus, for a given pipe geometry and material, the specific gravity of the fluid within the pipe may be determined by measuring the natural frequency of the tuning fork. The flow meter described has three digital displays for (1) specific gravity, (2) mass flow rate, and (3) totalized mass flow.

The Gyroscopic Mass Flow Meter can be used to measure the flow of gases, liquids, or non-homogeneous substances. It is insensitive to temperature and pressure and can be constructed using a variety of materials to provide the necessary corrosion resistance. The unit is perhaps the first real solution to the problems associated with the mass flow measurement of multiphase flow and cryogenic materials.

In laboratory tests on prototype units, accuracies in the order of ±0.2% fs have been recorded using fluids ranging in specific gravity from 0.5 to 2.5 and flow rates from 0.1 to 25 lb/min. The flow meter is linear to within ±0.2% fs over the total flow range. Tests have been conducted using both Newtonian and non-Newtonian fluids with a wide range of viscosities; the results indicate the meter is totally insensitive to viscosity.

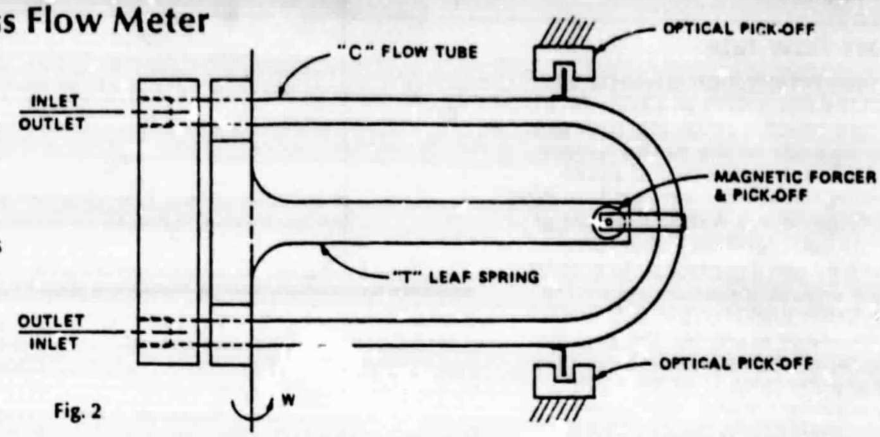


Fig. 2

The period of oscillation of a spring mass/system is given by:

$\tau = 2\pi m/k_s$ Equation (1)

Where τ is the period of oscillation, m is mass being oscillated, k_s is spring constant.

In the case of the pipe/leaf spring tuning fork of the Gyroscopic/Coriolis Flow Meter, the mass being oscillated can be divided into two parts:
(1) the mass of the pipe (m_p) and (2) the mass of the fluid in the pipe (m_f). In this case the period of oscillation is:

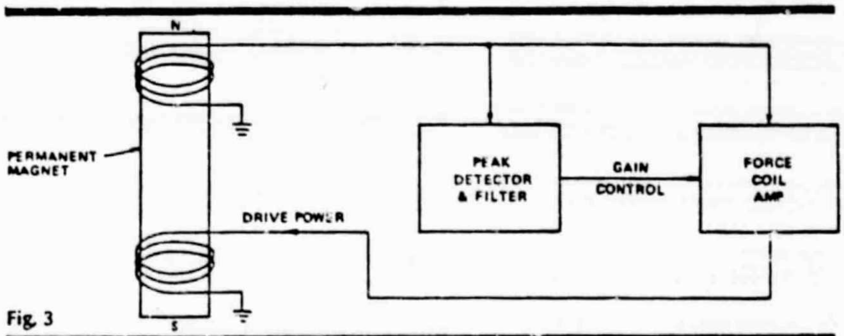


Fig. 3

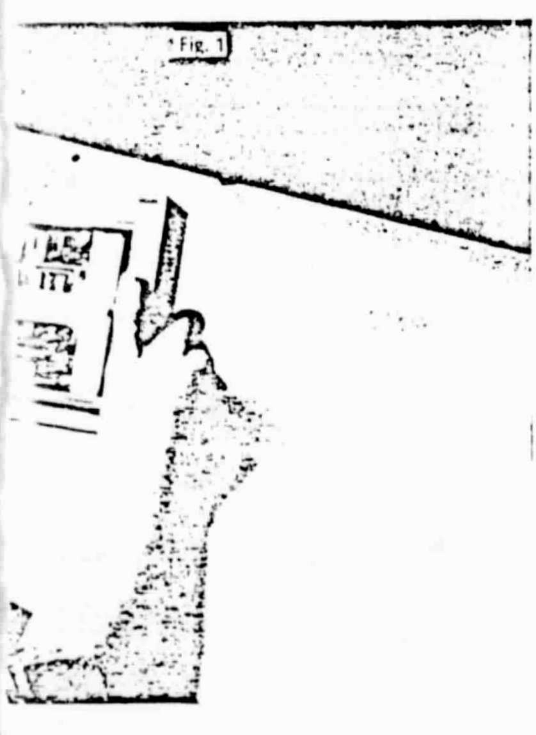


Fig. 1

How it works

The T-shaped leaf spring is clamped or welded to the stationary inlet/outlet end of the C-shaped flow pipe. A magnetic sensor/forcer coil is mounted on the leg of the leaf spring. A permanent magnet, suspended from the center of the C-shaped pipe, passes through the middle of the sensor/force coil. In operation, the velocity of the leaf spring relative to the C-pipe generates a voltage in the sense coil that is amplified and used to drive the concentric force coil. The force-coil amplifier is gain-controlled using a peak-detector circuit that compares the peak-velocity signal from the sense coil with a reference voltage (Fig. 3).

The pipe and leaf spring oscillate 180° out of phase with each other in the same way the tines of a tuning fork oscillate and, as in the tuning fork, little or no vibration is coupled into the base. The frequency of oscillation is determined by the natural frequency of the pipe/leaf spring; the amplitude is controlled by the peak detector circuit.

$\tau_1 = k_1 m_p + m_f$ Equation (2)

Where τ_1 is the period of oscillation of pipe/leaf spring and:

$k_1 = 2\pi/k_s$ Equation (3)

Since the mass of the fluid (Mf) is equal to the volume multiplied by the mass density, we can re-state Eq. (2) as:

$\tau_1 = k_1 k_2 + k_3 D_{fm}$ Equation (4)

Where k_1, k_2, k_3 are all fixed constants (defined by the geometry of the flowmeter), Dfm is the density of the fluid in the "C" pipe.

By counting the oscillations of a fixed-frequency oscillator during the time period (τ), a density factor (d_f) can be generated as follows:

$d_f = t_1 f_o = f_o k_1\ k_2 \times k_3 d_{fm}$

Where d_f is an indicated density factor and f_o is the frequency of the reference oscillator.

Although measuring density is not the primary objective of the mass flow meter, it is simple to display a density factor as outlined above. Given this density factor d_f, one may use Eq. (4) to determine the density of the fluid in the meter. As discussed in the following section, the accuracy

of the mass flow measurement does not depend on this density measurement.

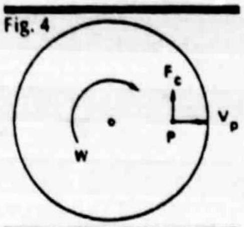
Mass flow rate

Coriolis acceleration is associated with the movement of a body on a surface which is revolving, such as a moving body on the earth's surface. Another example is that of a man walking radially outward on a rotating merry-go-round. A third example of Coriolis acceleration is that force which causes a gyroscope to precess when angular inputs are applied to axes other than the spin axis. In each of the above examples, the angular velocity of the reference surface (i.e., the angular velocity of the earth or of the merry-go-round) is constant.

With reference to Figure 4, the force on a particle due to Coriolis acceleration is given by:

$f_c = 2m_p \omega \times v_p$ Equation (6)

Fig. 4



Where f_c = force on particle due to Coriolis acceleration, m_p = mass of particle, v_p = velocity of particle, ω = angular velocity of reference plane.

As implied by the cross product ($\omega \times vp$), the Coriolis force (f_c) is perpendicular to the plane of ω and v_p. Two important factors should be noted from this: (1) the Coriolis force (f_c) is a linear function of the product $m_p v_p$ and (2) there are no restrictions on the angular velocity (ω): a negative ω would produce a negative Coriolis force (f_c) and, more important, an oscillating ω produces oscillating Coriolis force.

Fig. 5 is a sketch of the C-shaped pipe, showing both the axis of oscillation (ω) and a unit length of fluid within each leg of the pipe.

The velocity vectors (v_1) and (v_2) are perpendicular to the angular-rotation vector (ω), and that the Coriolis force vectors (f_{c1} and f_{c2}) are opposite in direction since the velocity vectors (v_1 and v_2) are opposite directions. In operation of the flow meter, the angular velocity (ω) is a sinusoidal function (as with any tuning fork) and the forces (f_{c1}) and (f_{c2}) are therefore sinusoidal and 180° out of phase with each other. Forces f_{c1} and f_{c2} create an oscillating moment (m) about axis "O". The moment can be expressed as a force time a distance.

$\Delta m = f_{c1} r_1 + f_{c2} r_2$ Equation (7)

If we assume a symmetrical geometry, the two terms are the same and

$\Delta m = 2 f_{c1} r_1 = 4 m_p v_p \omega r_1$ Equation (8)

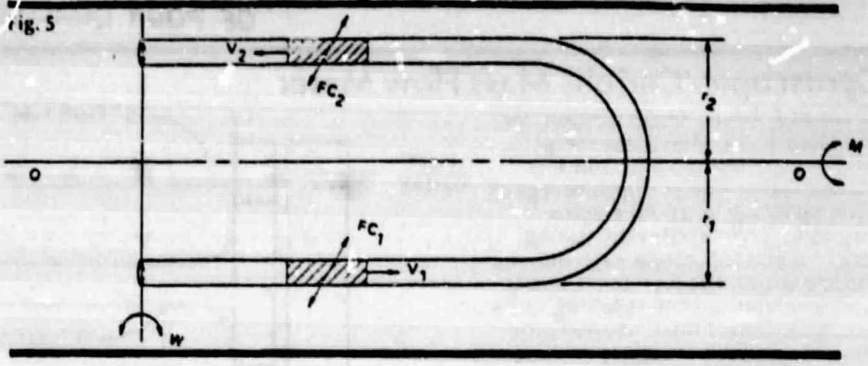
by substituting for f_c from equation 6. If we examine the units of $m_p v_p$ we find

$m_p \frac{\text{Lbs Mass}}{\text{Unit length}} v_p \frac{\text{Unit length}}{\text{Sec}} = \frac{\text{Lbs mass}}{\text{Sec}} = \Delta Q$

Where ΔQ is the incremental mass flow rate. Thus equation (8) becomes

$\Delta m = 4\omega r_1 \Delta_Q$ Equation (9)

Fig. 5



The total moment (m) about axis "O" due to Coriolis acceleration on all moving particles is given by:

$m = \Sigma\Delta m = \Sigma 4\omega r_1 \Delta Q = 4 \omega r_1 Q$ Equation (10)

Where Q is the mass flow rate in the C-shaped pipe.

The moment M due to Coriolis

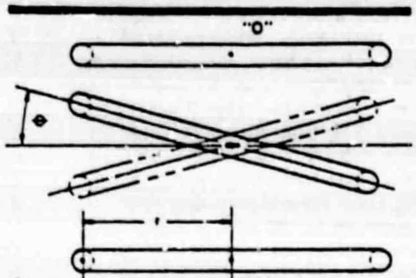


Fig. 6

acceleration causes an angular deflection of the C-shaped pipe about the central axis. This angular deflection can be examined using an end view of the C-shaped pipe (Fig. 6) which shows the resultant twist-type motion.

The deflection angle due to the moment M is determined by the spring constant of the C-shaped pipe system. This spring constant is a function of the cantilever stiffness of each longitudinal pipe and the torsional stiffness of each longitudinal pipe. For any given pipe system:

$\text{Torque} = k_s \Theta$ Equation (11)

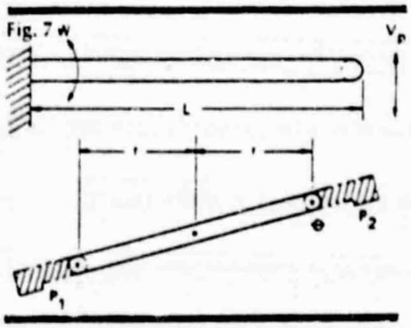
Where Θ is the pipe-system deflection ang[illegible]s the pipe system angular spri[illegible]stant.

Using thi[illegible]ati[illegible] we can relate the mass flow rate (Q) to the pipe deflection angle as follows:

$$Q = \frac{k_s \Theta}{4\omega r_1} \quad \text{Equation (12)}$$

At this point we find the mass flow rate (Q) directly proportional to the deflection angle (Θ) and inversely proportional to the angular velocity (ω) of the C-shaped pipe system. If we consider the optical pick-off system (Fig. 7), we can express Q as a function of Δt, the time interval between optical pulses as follows:

Fig. 7



The excursion of the C-pipe can be expressed as its velocity times the time interval (Δt) between photopulses (p_1 and p_2):

$v_p \Delta t = 2r\theta$

$$\text{or} \quad \Delta t = \frac{2r\Theta}{Vp} \quad \text{Equation (13)}$$

Where v_p = velocity of pipe at position of optical pick-offs, Δt = time interval that photo pick-off p_1 leads or lags p_2.

v_p, the vertical velocity of the end of the C-pipe, depends on the angular velocity (ω):

$v_p = L\omega$ Equation (14)

Where L is the length of the C-shaped pipe.

Combining equations (13 and 14):

$$\phi = \frac{L\omega\Delta t}{2r} \quad \text{Equation (15)}$$

Combining equations (12 and 15):

$$Q = \frac{K_s L\omega\Delta t}{8\omega r^2} = \frac{K_s L}{8r^2}\Delta t \quad \text{Equation (16)}$$

The mass flow rate is seen to be a function of pipe geometry constants at Δt, the time interval between photo-pulses. It can also be shown that, if the pipe has a zero-flow deflection angle Θ_0, this error is easily removed by comparing the time interval at Δt_1 of the downw[illegible]rd pipe movement with time interval Δ[illegible] of the upward pipe movement. If a no-flow condition exists, these time intervals subtract out, whereas a fluid flowing in the pipe causes different time intervals (depending on the direction of angular travel) that are detected as flow-induced pipe moments.

An important feature of the optical detection system is that deflection-angle measurements are made near the center position of the C-pipe travel. This is important because this is the time when the velocity and the deflection angle are the greatest. Also, this center position of the C-pipe is the position where the angular acceleration of the pipe is near zero, and any unbalance between pipes is least likely to cause an angular deflection that could be interpreted as flow signal. ■

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Engineering Study 304

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 304

ON-SITE INTEGRATION OF THE RCC MODIFIED ENGEL-PRECHT SEED REPROCESSING SYSTEM INTO ETF

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN-3-224

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SEPTEMBER 1981

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SCOPE:

A study was carried out to determine the desirability, feasibility and efficiency/cost impact of integrating the Resources Conservation Company (RCC) Modified Engel-Precht Seed Reprocessing System[1] into the ETF. The conceptual design described in the RCC Task #2 Report(1) and the conceptual design described in the MHD-ETF CDER(2) were combined by scaling the results published by RCC and by making minimal changes to each system. The goal in making changes was to maintain a high integrated plant efficiency and minimize costs.

FINDINGS:

The size and complexity of the Engel-Precht process results in a 5.8 percent increase in the capital cost, a 14.4 percent increase in the O&M costs, a decrease in efficiency from 38.03 to 37.15 percent and a 4.7 MW decrease in net power output. These impacts are offset by an operating expense savings of not buying fresh seed. The net effect is a small decrease in the cost of electricity of less than one percent (0.8 mills/kWhr). For the offsite nonintegrated plant, the savings are less and result in a decrease in the cost of electricity of less than one-half percent (0.4 mills/kWhr).

The effect of a number of process changes on the RCC design was also evaluated. The only change that has more than a minor effect on cost and performance is the removal of the module to separate sodium from spent seed. Removing this module leads to a net savings in the cost of electricity of 2.7 percent.

The integrated case involves risk exposure due to the additional capital involved and to the fact that the Modified Engel-Precht Process has not yet been developed for commercial use, consequently the options of purchasing seed and/or off site processing of seed, which entail a relatively small economic penalty should be considered as alternatives.

RECOMMENDATIONS:

This study has emphasized the engineering and economic (as opposed to the investment) aspects of seed regeneration. Prior to selecting a specific approach it is recommended that a self-consistent investment analysis be performed before a choice is made among the on-site, off-site and purchasing options. (Levelized costing analyses should also be conducted to see if the economic trade-offs remain the same.)

The economics of the Engel-Precht Process with the sodium removal module deleted seem favorable. A detailed engineering evaluation and design of this option should be performed.

Additional process analyses and pilot plant tests are needed for this process to reduce the technical and economic risks of development. However, prior to making a final decision in favor of the Engel-Precht Process, an on-site integration study for the Formate Process should be carried out.

PROCEDURE:

The Statement of Work for the study may be summarized as follows:

Subtask 1 - Establish a base case configuration for an integrated plant.

Subtask 2 - Prepare heat and mass balance diagrams for the base case conceptual design.

Subtask 3 - Prepare preliminary layout drawings for the base case conceptual design.

Subtask 4 - Assess the technical and economic impacts of integrating the Modified Engel-Precht Process into ETF.

Subtask 6 - Evaluate the efficiency and cost impacts of making changes to the Modified Engel-Precht Process.

Subtask 1 was completed early in order to provide a basis for carrying out the process engineering portion of Subtask 2. The resulting process mass balance was then used as a basis for carrying out the power engineering analyses needed to complete Subtask 2. The process engineering and power engineering portions of Subtask 2 were executed sequentially, and the remaining subtasks were executed in parallel.

The basic references for this study are the RCC Task #2 Report[1] and the MHD-ETF CDER[2], SDD-342.

The MHD-ETF CDER, SDD-342, describes the MHD-ETF Reference System which trucks spent seed to an off-site location for sale or reprocessing. The chemical process is unspecified. The RCC Task #2 Report describes the preferred process for reprocessing the spent seed.

The conceptual design described in the RCC Task #2 Report and the conceptual design described in the MHD-ETF CDER were integrated by making minor changes to each system. The flow rates of seed and ash from the MHD-ETF system were assumed as described in the MHD-ETF CDER, SDD-342. To the extent possible, the equipment described in the MHD-ETF CDER was retained. With minor exceptions, the RCC process was scaled from the results published in the RCC Task #2 Report.

In the area of MHD-ETF impact analysis, a rigorous analysis of the topping cycle using reprocessed seed was not carried out, but the steam cycle and flue gas distribution state points were rebalanced and revised. Similar limitations in scope were imposed in other areas of engineering analysis, but in all cases sufficient analysis work was carried out to make sure that no significant errors were introduced in the final cost and efficiency estimates for the integrated plant.

DISCUSSION:

1.0 SUMMARY:

1.1 PURPOSE

The ETF open-cycle MHD process uses potassium seeding (potassium carbonate and potassium sulfate) to increase the conductivity of the combustion gas. Potassium carbonate removes sulfur introduced by the coal. The purpose of the Engel-Precht Process is to transform the spent potassium sulfate back into potassium carbonate for re-injection into the MHD combustor in order to remove sulfur from the MHD gas stream.

The purpose of this study is to determine the desirability, feasibility and efficiency/cost impact of on-site integration of the Resources Conservation Company (RCC) Modified Engel-Precht Seed Reprocessing System into the ETF.

1.2 SUMMARY DESCRIPTION OF THE INTEGRATED SYSTEM

MHD power generation is based on the direct conversion of chemical heat energy to electricity by passing a high temperature, high velocity, electrically conducting fluid through a magnetic field.

Open cycle MHD has an advantage with respect to sulfur removal in that the potassium carbonate portion of the seed (which is injected into the combustion gas to increase its conductivity) reacts with the sulfur from the coal to form solid potassium sulfate (K_2SO_4). In the MHD-ETF system, which is described in the MHD-ETF CDER, the K_2SO_4 collects in the Heat Recovery/Seed Recovery (HR/SR) system and in the Electrostatic Precipitator (ESP), and a fraction is trucked off-site for reprocessing, sale, or disposal.

In the integrated system which is shown in Figure 1-1, a reprocessing plant is integrated with the MHD topping and steam bottoming cycles. The process shown in the figure is a modified Engel-Precht Process. Essentially pure potassium carbonate is produced. Very little potassium loss is foreseen, and there are no hazardous materials or high temperatures involved. Potassium losses from both the MHD cycle and the regeneration process are made up as KCl.

In the Engel-Precht Process, the sulfur from the coal is separated as calcium sulfate ($CaSO_4$), and the sodium which is an impurity from the coal, is removed as sodium chloride (NaCl). The potassium chloride (KCl) is converted to potassium bicarbonate ($KHCO_3$) and the magnesium (which is a necessary participant in the Engel salt formation and decomposition reactions) is recovered.

On the basis of previous studies, the choice between available seed regeneration processes was narrowed down to two - the Formate Process and the Engel-Precht Process. Based on the results of the RCC Task #1 Report[3], the Modified Engel-Precht Process was selected and fully described in the RCC Task #2 Report[1].

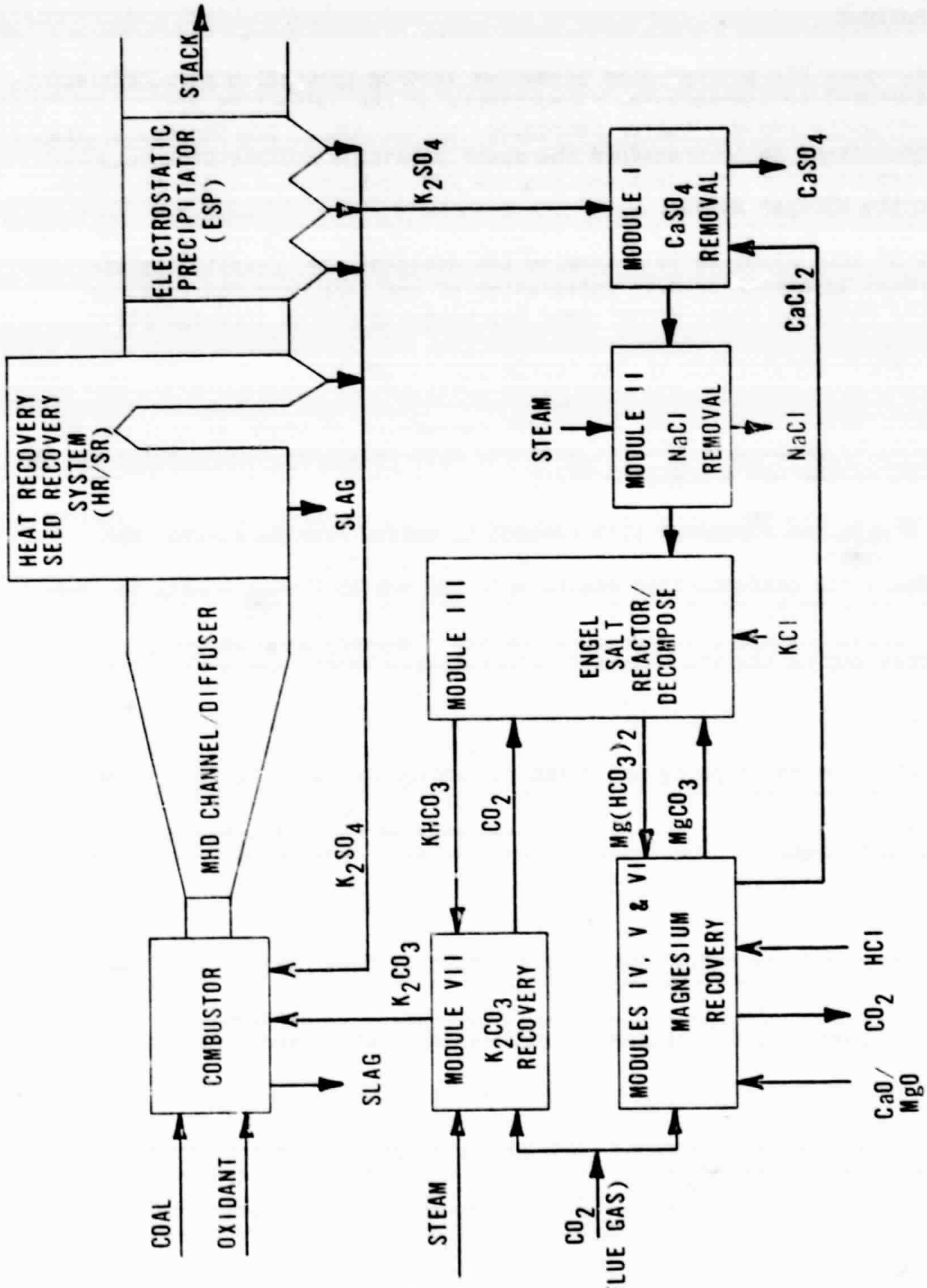

FIGURE 1-1
ENGEL-PRECHT PROCESS INTEGRATED WITH MHD-ETF

In order to provide the ETF system with the necessary 7,992 lb/hr of fresh seed the modified Engel-Precht requirements were found to be as follows:

Electrical Power	2,585 kW
Steam (100 psig)	5,735 lb/hr dry saturated
Steam (60 psig)	15,130 lb/hr dry saturated
Flue Gas (CO_2)	27,331 lb/hr at 150°F
Flue Gas (drying)	80,280 lb/hr at 480.9°F
Heat Rejection (cooling tower)	22.6×10^6 Btu/hr

Integrating the seed reprocessing unit into the ETF cycle reduces the steam turbine generator power produced due to new steam extractions for process use. Steam extraction is also required for heating feedwater which was previously heated by means of flue gas. In addition, auxiliary power was increased to meet the electrical demand of the process.

The net result of integrating the seed reprocessing plant into the ETF cycle is a 0.88 point drop in efficiency to 37.15 percent and a 4.7 MW decrease in net power output. The reduced efficiency and added cost for the on-site regeneration plant were offset by an operating expense savings of not buying fresh seed on the open market. The net effect was a cost of electricity savings of less than one percent (0.8 mills/kWh).

Several possibilities for extracting low grade heat from the ETF power plant were considered, but in all cases the impact on net plant efficiency or on equipment cost (due to inadequate temperature differences) could not be justified in terms of reduced cost of electricity.

1.3 SUMMARY ASSESSMENT OF POTENTIAL FOR PROCESS MODIFICATIONS

The only process change that has more than a minor impact on performance and cost is the removal of the sodium rejection module. Removing the module resulted in a net savings in the cost of electricity of 2.7 percent (2.6 mills/kWhr). For this study, the sodium concentration reported in the MHD-ETF, SDD-342, for the case of steady state recycle of the seed was assumed. Removing the sodium rejection module would cause the steady state value of the sodium content in the recycled seed stream to increase somewhat. Removing this module would also complicate the solid waste disposal problem since soluble sodium would contaminate this waste. A detailed engineering evaluation is needed to determine the effects of deleting the sodium rejection module on both the Engel-Precht Process and the MHD cycle. A detailed engineering evaluation is needed to determine the effects on the MHD cycle and the Engel-Precht Process. Pilot plant tests are needed to provide process and cost data, but the potential economic benefits warrant the additional work necessary to accomplish this.

2.0 PROCESS ENGINEERING

2.1 BASIS FOR DESIGN

2.1.1 Spent Seed Composition

The spent seed composition assumed by RCC was specified in terms of K_2SO_4, K_2CO_3 and fly ash mass flow rates. In addition, the flow rates of a number of ions (K, Na, Pb, Zn, Cl, Fe and P) were specified.

In order for RCC to initiate their study it was necessary for them to estimate a spent seed composition in terms of specific compounds. An estimated composition was established early in the RCC study as a result of discussions between RCC and Argonne National Laboratory. The resulting composition is shown in Table 2-1.

For comparison purposes the spent seed composition from the MHD-ETF CDER is shown in Table 2-1. The two compositions are different. This is because the concentrations of Na, Zn, Pb, Fe and P given to RCC were estimated by assuming that these impurities had accumulated in the seed recycled many times through a regeneration process that separated sulfur from the potassium but did not separate the impurity elements. The RCC process separates a higher fraction of impurities, especially sodium, than would be required to maintain acceptable steady state impurity levels in recycled seed. In addition, the chemical composition of the spent seed depends upon coal composition, the ratio of K_2CO_3 to the sulfur in the coal, the species that are assumed to be present when the equilibrium compositions are estimated, and the assumed impurity accumulation rate.

As a result of the limited scope of the study, the spent seed composition shown in the MHD-ETF CDER, SDD-342, was assumed. This seed composition is based on the ETF coal composition and assumed the steady state recycle of spent seed. This leads to a high sodium concentration due to the fact that concentrations reported in SDD-342 were not based on the Engel-Precht Process. However, the differences between these high sodium seed compositions and the lower sodium seed composition attainable do not affect the results of this study significantly.

2.1.2 The Engel-Precht/ETF Interface

The "Seed Management System" (SDD-342 CDER[2]) includes a partial recycle of recovered spent seed and flyash to the combustor along with makeup of K_2CO_3. An alternative to this makeup is to regenerate the previously discarded material. Consider Figure 1-1 in SDD-342, here reproduced as Figure 2-1. The 16,821 lb/hr direct recycle stream is continued. The 11,068 lb/hr discard stream is now directed to regeneration as shown in Figure 2-2. The regeneration plant utilizes CO_2 from the MHD/ETF combustion gas. Approximately 75 percent of the flue gas is used for product drying and 25% supplies CO_2 to the Engel-Precht Process Plant. Fresh KCl, HCl, MgO, CaO and steam are fed into the Engel-Precht Process to convert K_2SO_4 to K_2CO_3 and to remove sulfur as gypsum filter cake and sodium as NaCl.

TABLE 2-1

SPENT SEED PERCENTAGE COMPOSITION BY WEIGHT

	RCC Study (Montana Coal)	MHD-ETF (SDD-342)
K_2CO_3	1.49	1.29
K_2SO_4	70.40	77.53
Na_2SO_4	20.88	-
KPO_3	0.76	-
K_2SiO_3	0.04	-
$K_2Si_4O_9$	0.08	-
K_2AlSiO_4	1.70	-
Fe_2O_3	4.55	
Z_nCl_2	0.09	-
$PbSiO_3$	0.01	-
Al_2O_3	-	0.47
$CaCO_3$	-	1.08
Fe_3O_4	-	1.13
$MgCO_3$	-	0.43
Na_2CO_3	-	14.48
$KAlSi_3O_8$	-	3.59

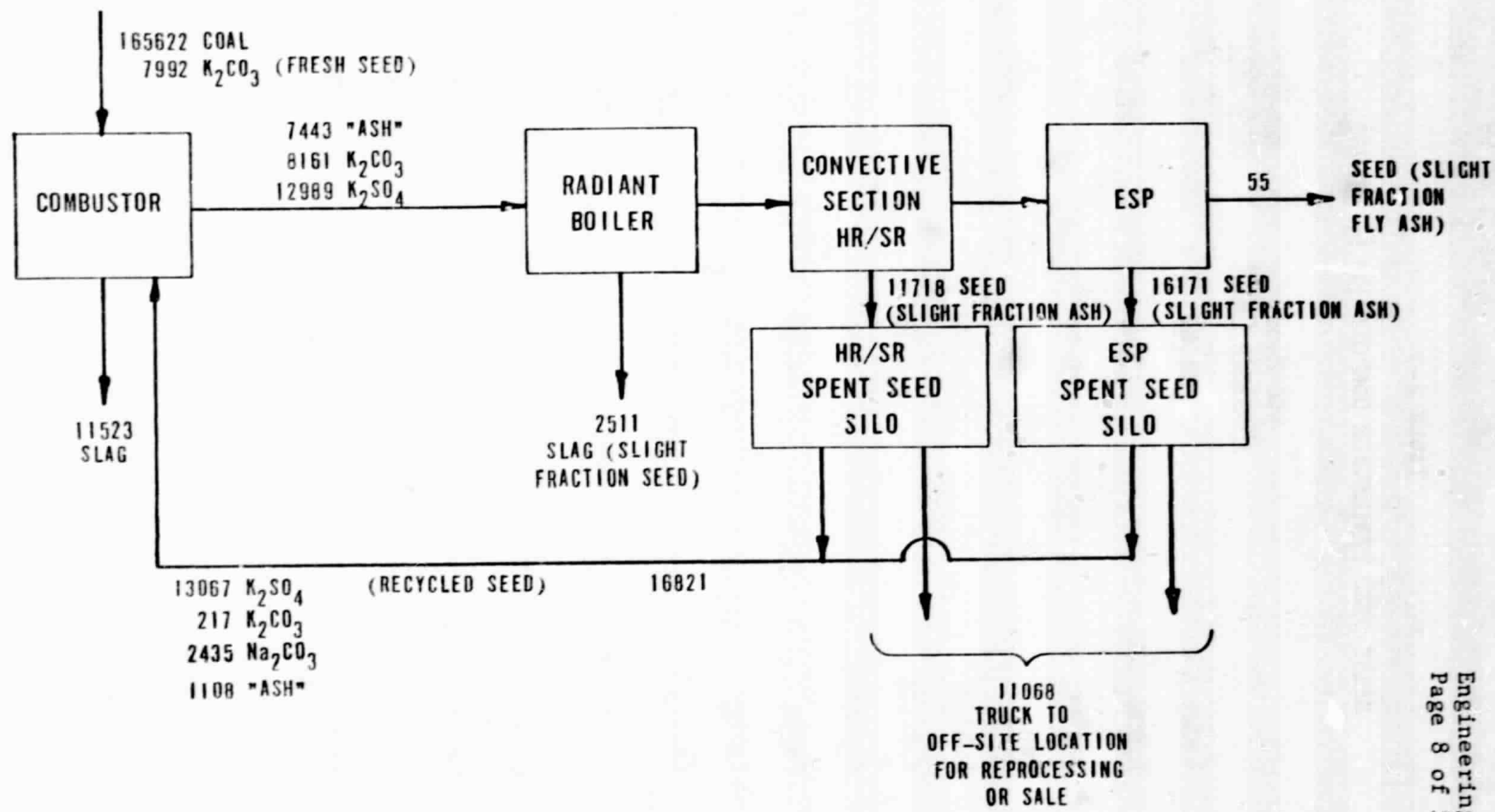

FIGURE 2-1
DOMINANT FLOWS (IN LB/HR) IN THE ETF REFERENCE SEED MANAGEMENT SYSTEM WHICH EMPLOYS PARTIAL RECYCLE OF RECOVERED SEED

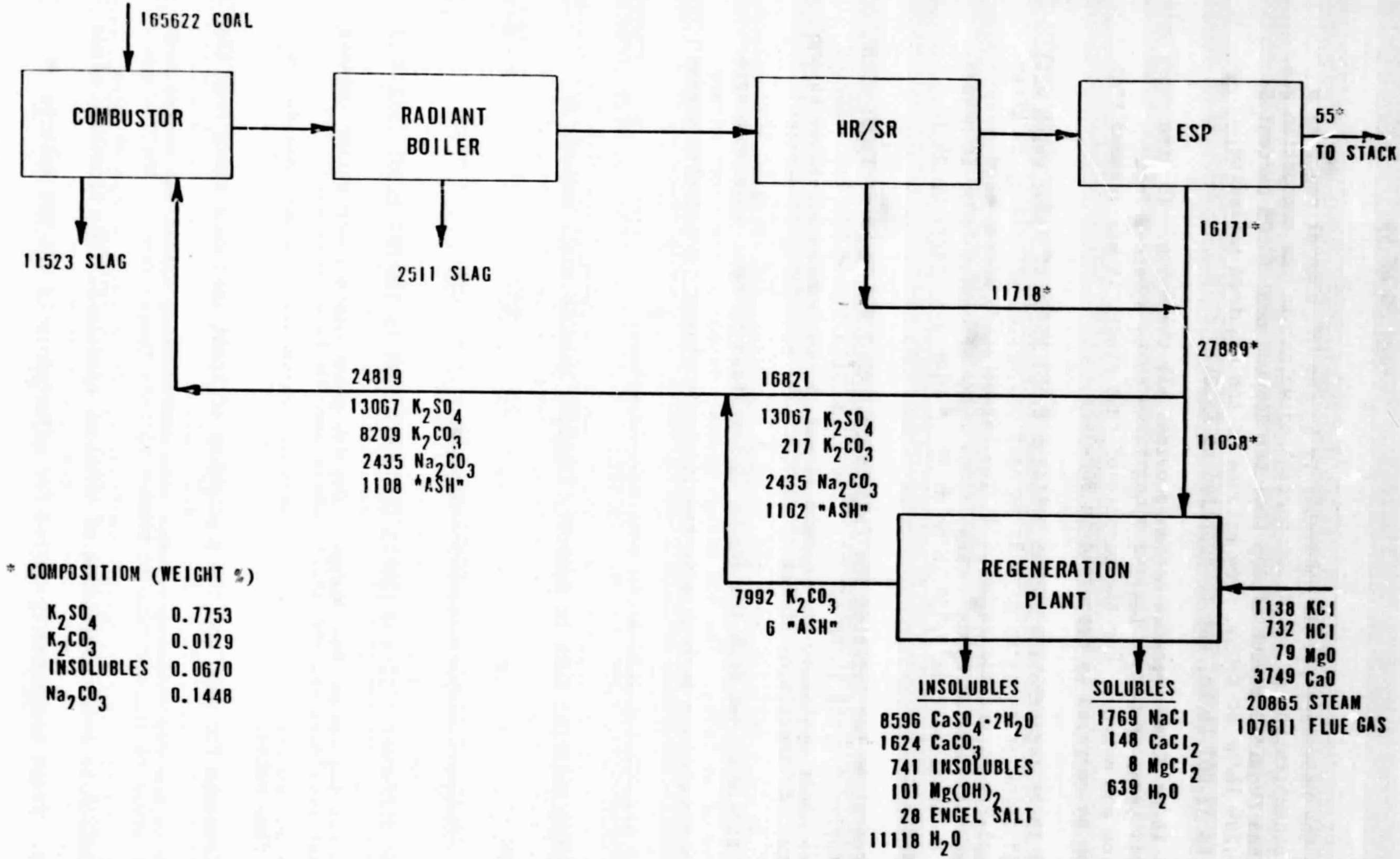

FIGURE 2-2 DOMINANT FLOWS (IN LB/HR) IN ETF SEED REGENERATION CASE

To achieve the necessary plasma conductivity in the MHD channel requires a potassium concentration of about one percent by weight in the combustion gas. To remove the required amount of SO_2 from the Rosebud coal (1.05 percent S) requires 8,209 lb/hr of K_2CO_3. The balance of the required potassium, amounting to 13,067 lb/hr, can be supplied as K_2SO_4.

The 16,821 lb/hr direct recycle stream provides all the K_2SO_4. It also provides 217 lb/hr of K_2CO_3, leaving 7,992 lb/hr to be obtained from regeneration and makeup. For the purpose of this study, it was assumed that the ash can be recycled as described in SDD-342.

The 11,068 lb/hr regeneration stream contains 8,581 lb/hr of K_2SO_4 which will yield 6,797 lb/hr of K_2CO_3 at a 99.88 percent conversion efficiency as given by the Engel-Precht process report.(1) The regeneration stream also contributes 144 lb/hr of K_2CO_3. Thus, 1,051 lb/hr of makeup K_2CO_3 is needed. This will be obtained from 1,138 lb/hr of KCl, which also makes up other system losses.

Thus, regeneration has replaced the fresh supply of 7,992 lb/hr of K_2CO_3 with a fresh supply of 1,138 lb/hr of KCl. The disposable stream has been changed from 11,068 lb/hr contained in a single stream (to be trucked off-site) to two new streams. An insolubles stream of 22,180 lb/hr containing 50 percent solids can go to a settling pond and on to a landfill. The $CaCO_3$ in the insoluble stream arises from the Na_2CO_3 in the input stream. This carbonate is disposed of as $CaCO_3$. The RCC design assumed Na_2SO_4 as the input stream and thus had much less carbonate in the insoluble stream. A solubles stream of 2,564 lb/hr containing 75 percent solids can go to a lined, leachate controlled evaporation pond or to deep well injection.

The amount of chloride impurity returned to the MHD topping cycle with the recycled seed material must be severely limited, because small amounts of chlorine reduce the plasma conductivity and therefore the efficiency of the MHD system.

2.1.3 Basis for Process Equipment Scaling

Since the seed reprocessing system described in the RCC Task #2 Report(1) is based upon different sizing criteria (450 MWt) than is the MHD plant (532 MWt) described in the MHD-ETF CDER(2), it was necessary to scale the smaller RCC design to fit the larger MHD design. The RCC plant has a lower sulfur content in its coal than does the ETF plant, which results in a lower seed regeneration requirement for the RCC plant. Generally, equipment was scaled based on flow rates.

The requirements for seed and the production of spent seed were taken from the MHD-ETF CDER. The spent seed amount and analysis were assumed to be available for input to the reprocessing system. The reprocessing system was scaled from the input given in the RCC Task #2 Report to this larger input. Scaling was generally done by ratio of Gilbert Associates, Inc. amounts to RCC amounts with attention to proper balancing of chemical reactions. Additionally, since the RCC and GAI coal analyses were different, allowances for this difference were made. These occasionally called for adjustments in the RCC amounts

before scaling. Liquid flows were simply ratioed, but the amounts of water retained in filter and centrifuge cakes were increased from 20 percent and 3 percent to 50 percent and 25 percent, respectively.

These are conservative estimates based upon GAI experience in designing ash handling and flue gas desulfurization sludge disposal systems. The MHD flue gas, which contained 31 percent CO_2, was the source of the CO_2 needed in the process. Also, the process steam condensate was used as makeup, eliminating any need for process water makeup. The remaining RCC assumptions were retained. They are as follows:

0.3 lb. washwater/lb. crystals on filters
2 lb washwater/lb crystals in $Mg(OH)_2$ wash tower
10% $Mg(OH)_2$ slurry from thickener
40% slurry from decomposer
2.43 lb. water/lb. Engel salt decomposed
40% of CO_2 in stack gas absorbed

2.2 ENGEL-PRECHT PROCESS DESCRIPTION

A simplified block diagram of the process is shown in Figure 2-3. In Module I spent seed is dissolved and mixed with calcium and potassium chlorides. The calcium sulfate and other insolubles are discarded, and the chlorides of sodium and potassium are sent to Module II.

In Module II the chlorides are concentrated by evaporation and separated, and the sodium chloride is sold as a by-product.

In Module III, in the presence of magnesium carbonate and carbon dioxide, the potassium chloride is converted to Engel salt ($KHCO_3 \cdot MgCO_3 \cdot 4H_2O$) at 65°F. At 160°F the Engel salt breaks down into potassium bicarbonate and magnesium carbonate.

In Module VII, potassium carbonate is recovered from the bicarbonate, and in Modules IV, V and VI the magnesium is recovered for re-use and the calcium/potassium chlorides are recycled back to Module I.

A brief description of each module follows.

2.2.1 Module I - Dissolution of Spent Seed

The Module I subsystem is shown in Figure 2-4. Spent seed is slurried in a slurrying tank, and pumped into a baffled mix tank along with the calcium chloride/potassium chloride recycle stream (4) from Module V, gypsum, potassium/sodium chlorides from Module II, and combined blowdowns (6).

Overflow from the dissolver/reactor flows into a settling tank. The bottoms drain into a filter where they are washed with stream (8) and dewatered to about 50 percent moisture. The filter cake (9) is conveyed to the battery limits and the filtrate is returned to the slurrying tank.

The overflow (7) from the settling tank flows to a feed tank in Module II.

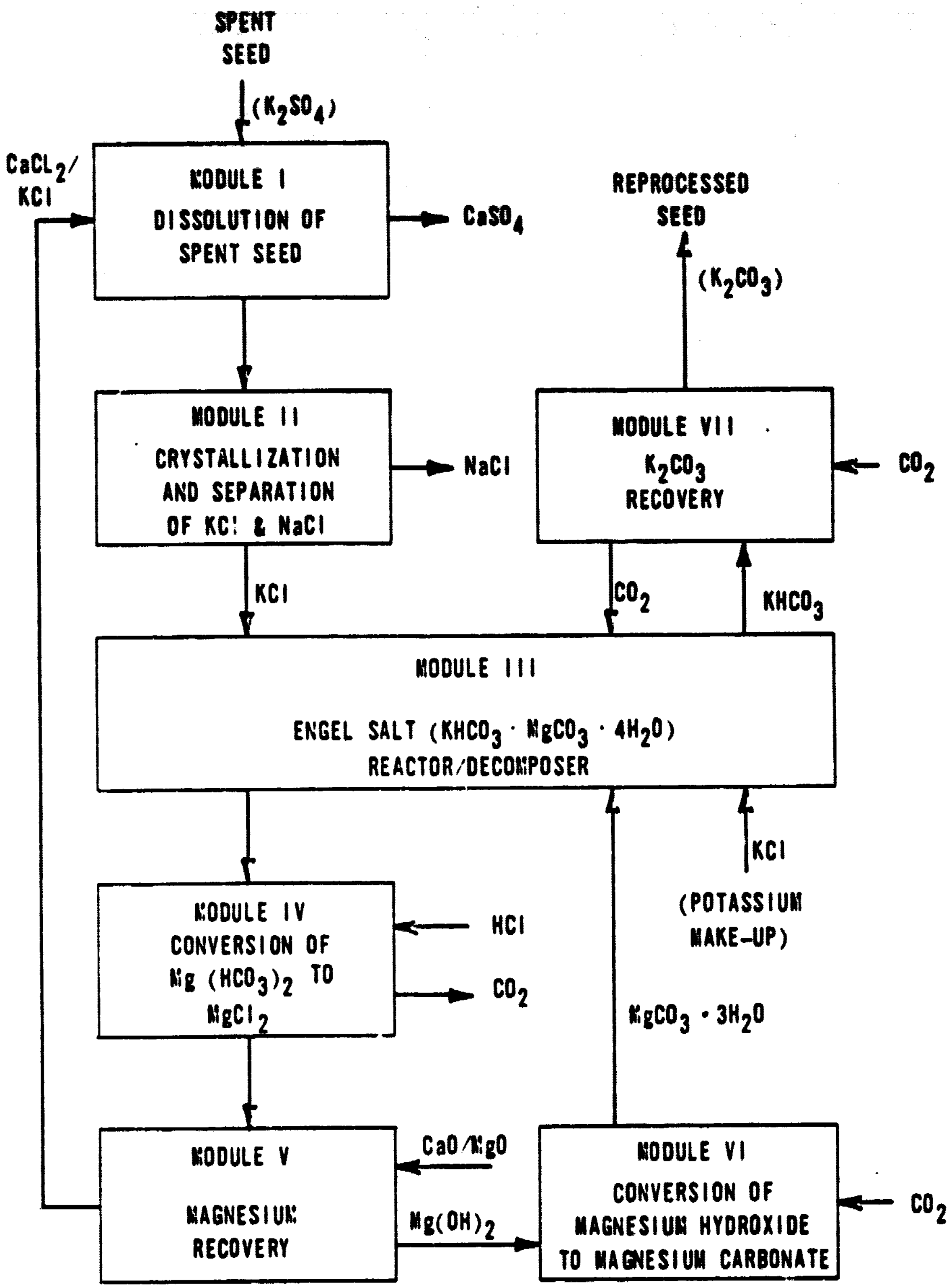

FIGURE 2-3
THE MODIFIED ENGEL-PRECHT PROCESS

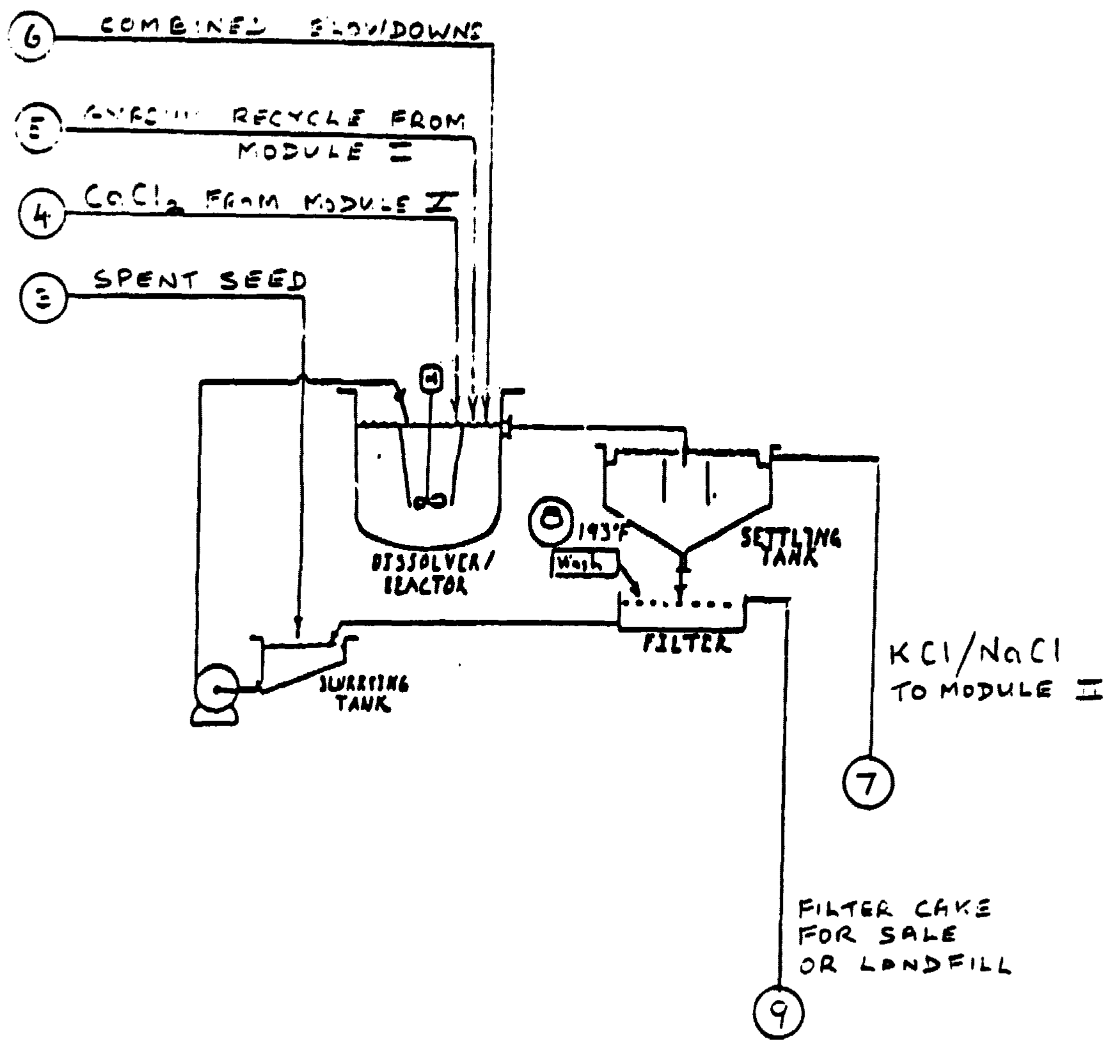

FIGURE 2-4

MODULE I - DISSOLUTION OF SPENT SEED

2.2.2 Module II - Crystallization and Separation of Sodium and Potassium Chlorides

The primary purpose of Module II, which is shown in Figure 2-5, is to evaporate water from the KCl solution. At the same time sodium chloride is crystallized out of solution and removed from the system.

KCl/NaCl solution (7) from Module I enters a feed tank from which it is pumped through a heat exchanger into a vapor compression pre-evaporator. Hot condensate from the evaporator and following crystallizer is cooled by heat exchange with the feed, and is saved for use as wash water (15).

The concentrated potassium/sodium chloride solution, nearly saturated with respect to potassium chloride, is run into a multiple effect crystallizer. The fourth effect of the crystallizer concentrates the solution near the KCl saturation level. KCl crystals which are removed from the third effect are dewatered to about 25 percent (18) and sent to Module III. Further concentration occurs in the second effect to the point of NaCl crystallization. NaCl crystals settle into an elutriation leg and flow to a centrifuge where they are washed and dewatered to 25 percent moisture (17). Liquor is drawn off the first effect and sent to a cyclone separator. The cyclone bottoms, containing NaCl crystals, are sent back to the first effect, and the clarified stream is flashed to a lower temperature, where KCl is now less soluble than NaCl. KCl crystals are settled out in the settling tank and sent to the KCl centrifuge. Hot condensate from the last three effects is cooled and used as wash water (15).

2.2.3 Module III - Engel Salt Reactor/Decomposer

The primary purpose of this module, which is shown in Figure 2-6, is to convert potassium chloride (18) into potassium bicarbonate (43).

Potassium chloride is mixed with cold recycled magnesium carbonate slurry and make-up potassium chloride. In the presence of CO_2, Engel salt, and magnesium carbonate crystals settle out. The finer magnesium carbonate crystals are washed back up into the reactor, and the Engel salt flows from the elutriation leg to a centrifuge. These crystals are reslurried with water at a higher temperature in order to decompose them into potassium bicarbonate and magnesium carbonate. The potassium bicarbonate overflow is pumped to Module VII. The underflow (mainly $MgCO_3 \cdot 3H_2O$) is saturated with carbon dioxide, flash cooled to 105°F, mixed with magnesium carbonate from the carbonating tower (33) and vacuum flashed to 32°F before being returned to the Engel salt reactor.

As a result of the reactions taking place in the Engel salt reactor, magnesium chloride is formed. This (together with potassium chloride and some magnesium bicarbonate) is sent to Module IV.

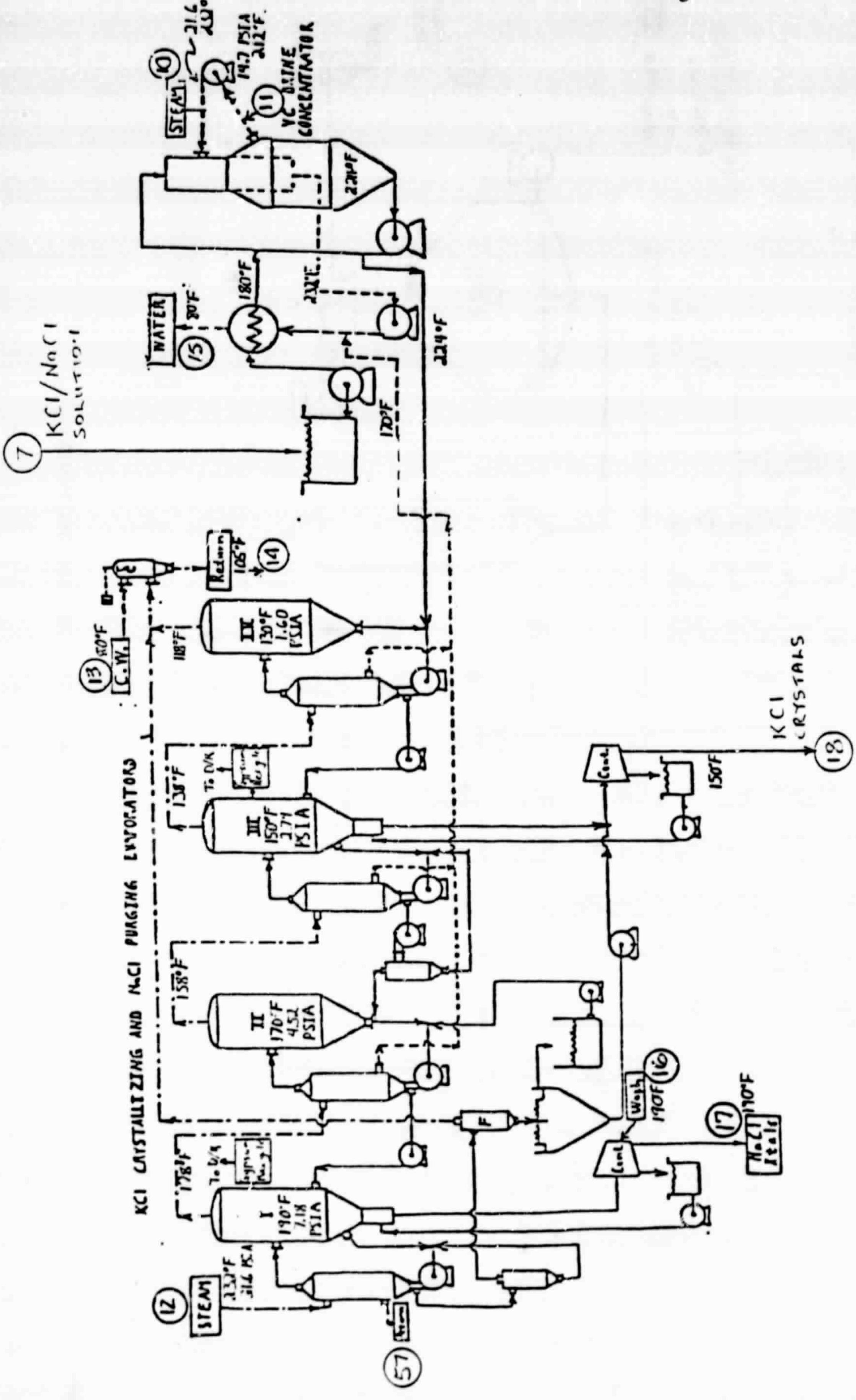

FIGURE 2-5

MODULE II - CRYSTALLIZATION AND SEPARATION OF SODIUM AND POTASSIUM CHLORIDES

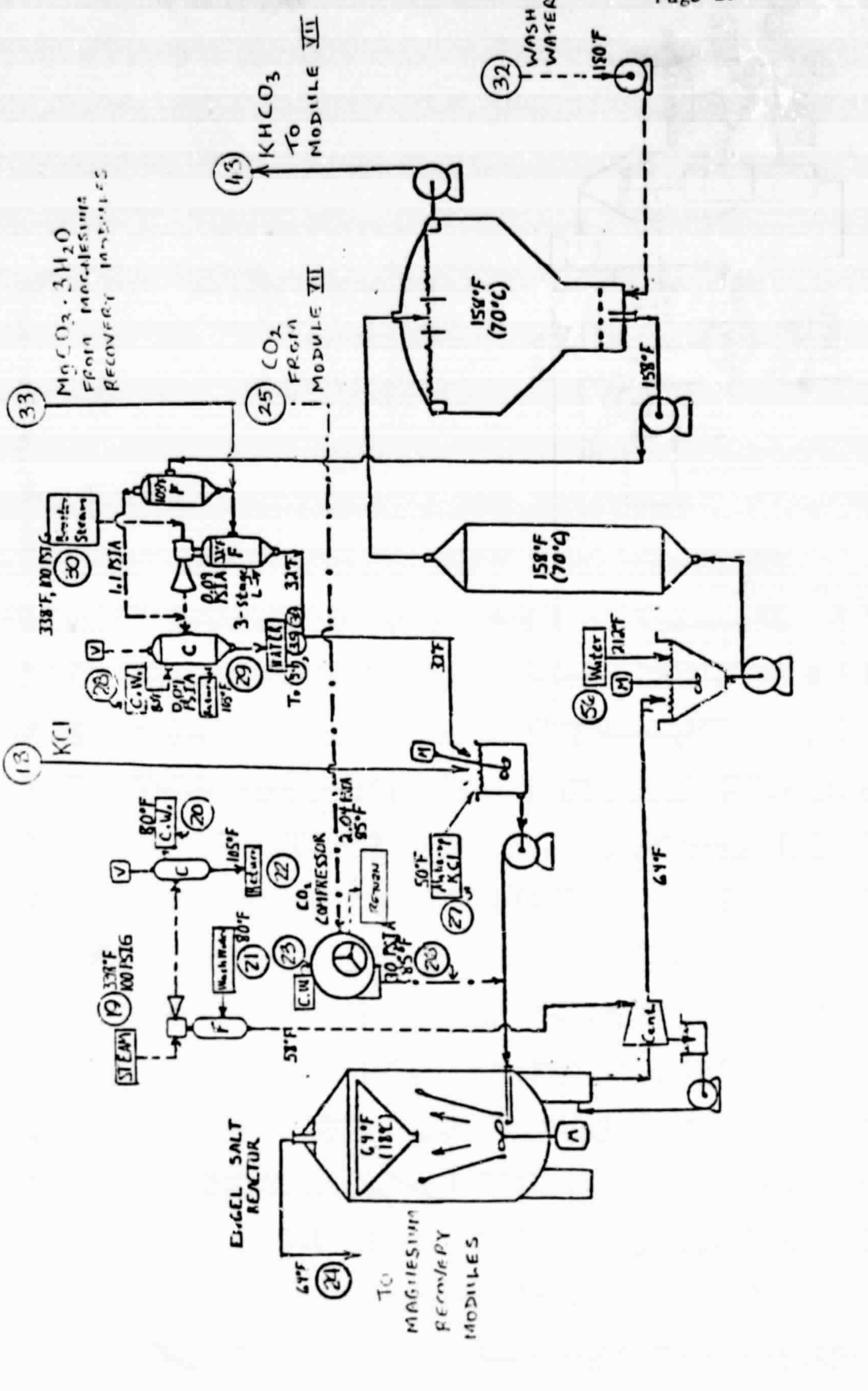

FIGURE 2-6

MODULE III - ENGEL SALT REACTOR/DECOMPOSER

2.2.4 Module IV - Decarbonation of Magnesium Bicarbonate

The purpose of this module, which is shown in Figure 2-7, is to convert the magnesium bicarbonate in stream 24 to magnesium chloride in stream 37. The feed solution (24) is mixed with hydrochloric acid in a mix tank, and run through a stripping column where the carbon dioxide is stripped off by means of a countercurrent flow of air (35).

2.2.5 Module V - Magnesium Hydroxide Recovery

The purpose of this module is to recover the magnesium as the hydroxide, and to return the KCl and $CaCl_2$ to Module I, as shown in Figure 2-8.

The decarbonated stream (37) flows into a lime treat tank where lime and make-up magnesia are added. Magnesium, in solution as chloride, is precipitated as hydroxide and the slurry sent to a clarifier/thickener. The overflow (4) containing calcium and potassium chlorides is returned to Module I. The underflow, $Mg(OH)_2$, is pumped to a wash tower (in order to remove any remaining brine) and then sent to Module VI.

2.2.6 Module VI - Conversion of Magnesium Hydroxide to Magnesium Carbonate

Module VI is shown in Figure 2-9. The washed magnesium hydroxide is pumped to the top of a carbonating tower. Stack gas, assumed to contain 31 percent carbon dioxide, is bubbled through the tower, which is designed to absorb 40 percent of the carbon dioxide. Magnesium carbonate flows from the bottom of the carbonating tower into an age tank. The purpose of the age tank is to allow the growth of larger magnesium carbonate trihydrate crystals, which prevent excessive thickening in the Engel salt reactor. The overflow, containing the smaller crystals, is recycled back to the carbonating tower. The larger crystals are pumped out near the bottom (33) and sent to Module III.

2.2.7 Module VII - Potassium Carbonate Recovery

The primary purpose of this module, which is shown in Figure 2-10, is to evaporate water from the potassium bicarbonate stream (43) and return carbon dioxide to the Engel salt reactor. The amount of carbon dioxide required, however, is short by one-half the carbon dioxide lost in Module IV, stream 36. In order to make up for this carbon dioxide, a slip stream of feed (stream 43) is reconverted to bicarbonate by running it through an absorber in contact with stack gas. The subsequent decomposition of the bicarbonate in the vapor recompression evaporator then supplies the necessary make-up carbon dioxide (26) for the Engel salt reaction.

The main potassium bicarbonate feed stream (43) is concentrated in a vapor recompression evaporator where the bicarbonate is decomposed to potassium carbonate and carbon dioxide. The potassium carbonate then flows to a steam heated, falling film, vertical tube evaporator. The concentrate is sent to a steam heated forced circulation crystallizer. From the crystallizer, a stream containing potassium carbonate crystals is centrifuged to nearly dry potassium

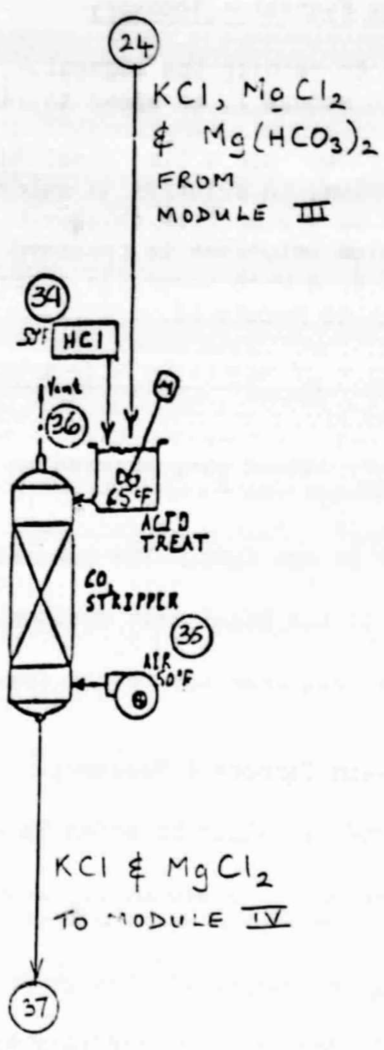

FIGURE 2-7

MODULE IV - DECARBONATION OF MAGNESIUM BICARBONATE

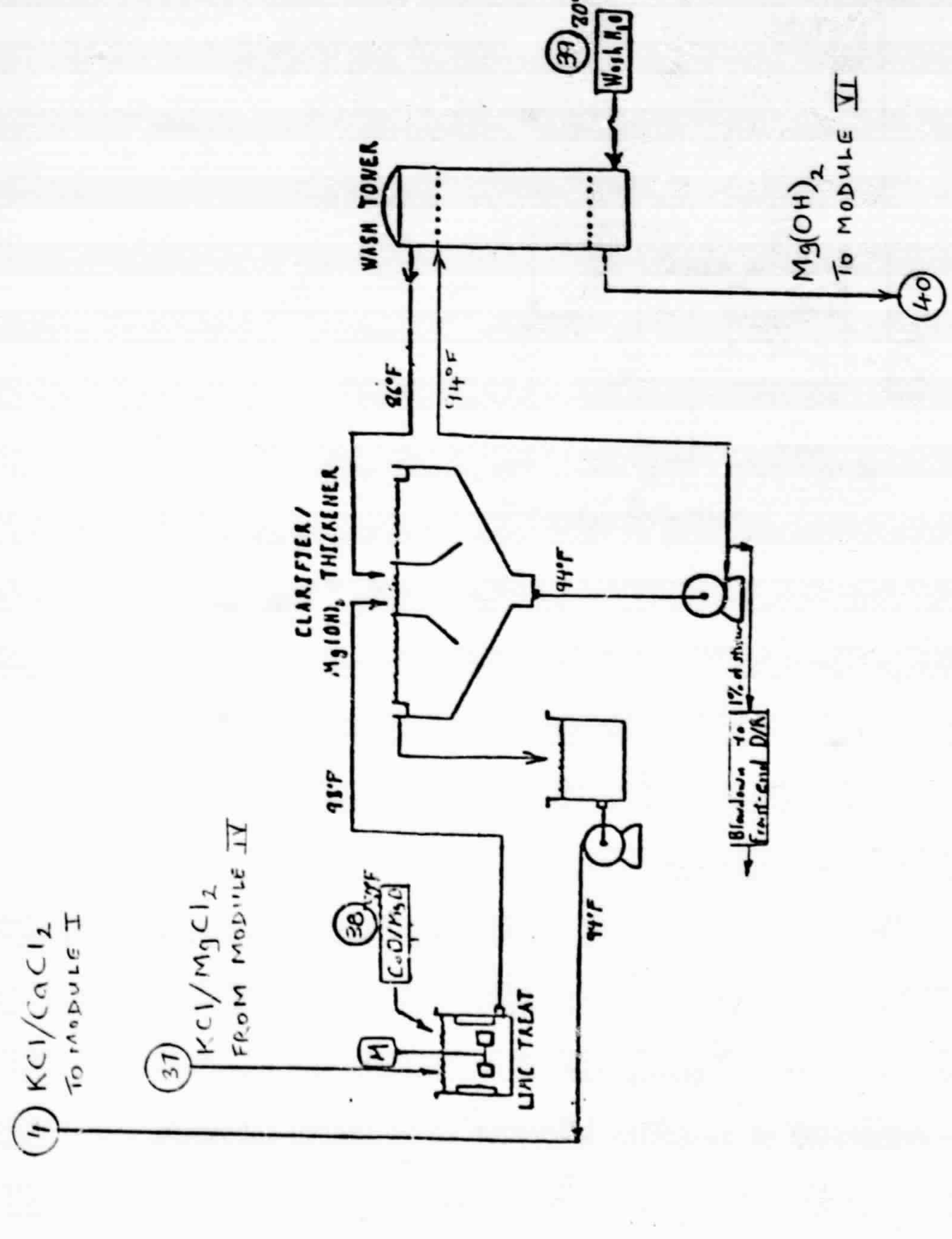

FIGURE 2-8

MODULE V - MAGNESIUM HYDROXIDE RECOVERY

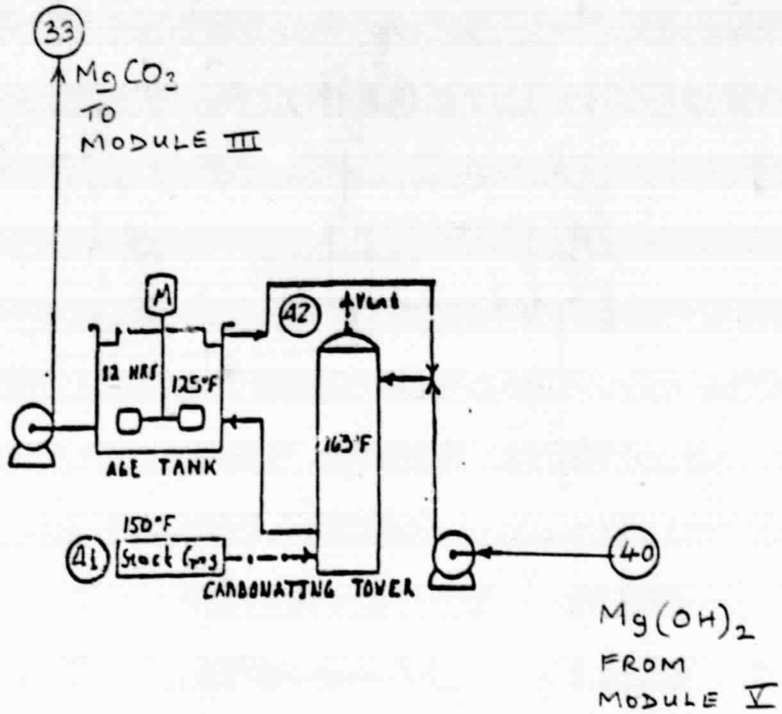

FIGURE 2-9

MODULE VI - CONVERSION OF MAGNESIUM HYDROXIDE TO MAGNESIUM CARBONATE

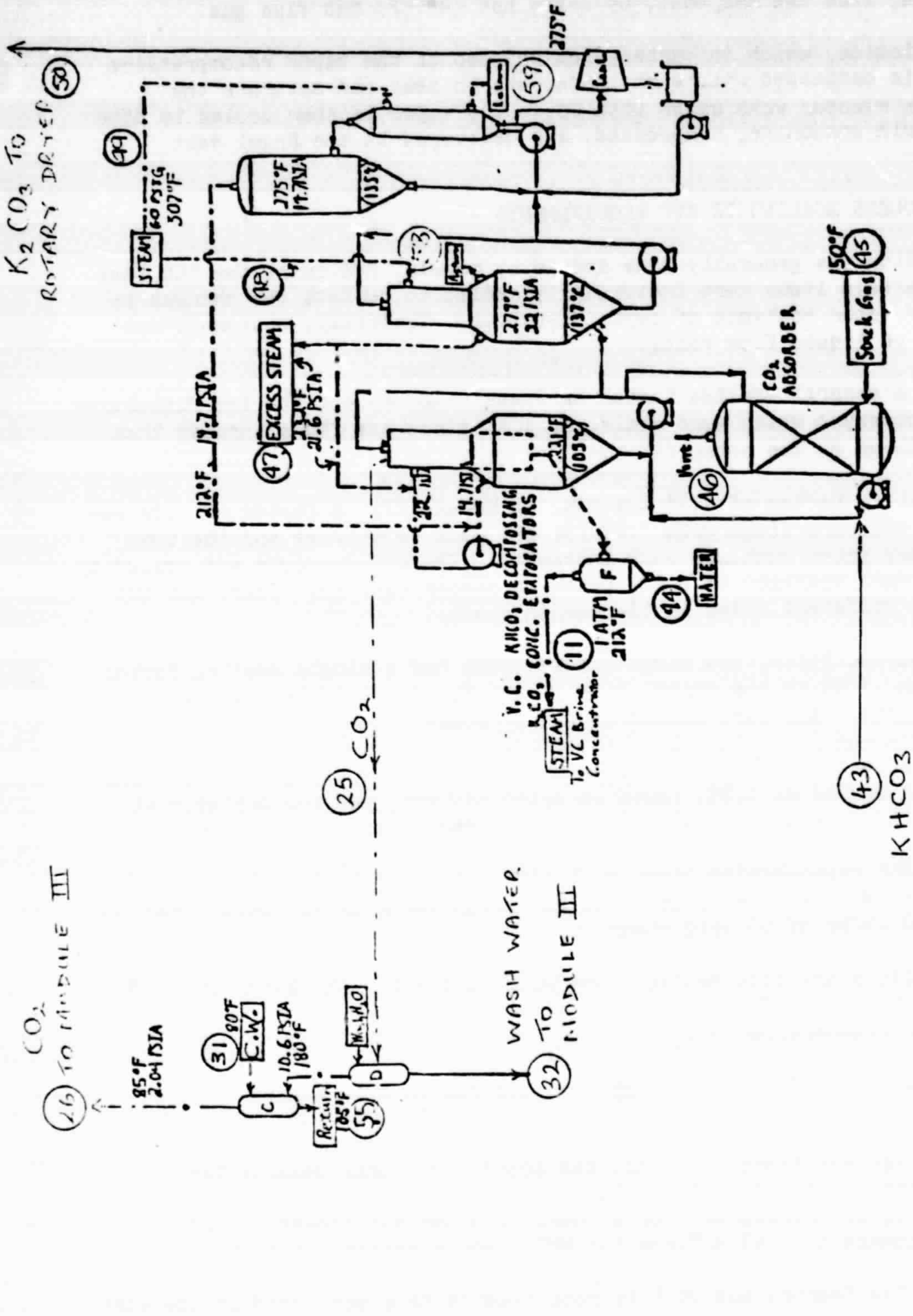

FIGURE 2-10

MODULE VII - POTASSIUM CARBONATE RECO ERY

carbonate, which is conveyed to the rotary dryer near the MHD combustor. The seed is dried, like the MHD coal, by using hot (497°F) MHD flue gas.

The carbon dioxide, which is vented from the top of the vapor recompression evaporator, is contacted with warm condensate to heat and saturate the decomposition reactor wash water with CO_2. The vapor is then cooled to 85°F in a barometric condenser, compressed, and delivered to the Engel salt reactor.

2.3 PROCESS SCALING TO ETF REQUIREMENTS

Although scaling was generally done module by module, following the RCC Task #2 Report, certain items were individually scaled to reflect the changes in solids and/or water contents of certain streams. Generally, equipment was scaled based on liquid flow rates.

In Module I, a general scaling factor of 2 was used, except for the dissolver-reactor and conveyor which were scaled at 1.5, since the flows through them were not as large as the other flows.

A general scaling factor of 1.46 was used in Module II. A factor of 1.74 was used for the KCl centrifuge with 1.88 for the NaCl centrifuge and the sump pump since cake water contents were increased. The KCl conveyor was scaled by 1.33 and the NaCl conveyor by 0.20, based on masses carried. Thus, the two conveyors are different sizes in the scaled plant.

The third, fourth, fifth, and sixth modules each had a single scaling factor for every item, 1.55 in the third, 1.44 in the fourth, 1.41 in the fifth, and 1.43 in the sixth. All were scaled on fluid flows.

Only two items in the last module, VII, had individual scaling factors. The centrifuge was scaled at 1.75, based on water content, and the conveyor at 2.14, due to the increased mass carried. All other items were scaled at 1.44.

The Engel-Precht reprocessing plant will also require utilities from the MHD plant. Two steam lines are needed, one for 5,735 lb/hr of 100 psig steam and one for 15,130 lb/hr of 60 psig steam.

Two flue gas lines are also needed. One will supply 27, 332 lb/hr of 150°F flue gas as a source of CO_2. The other will supply 80,280 lb/hr of 497°F flue gas to dry the regenerated K_2CO_3.

A cooling water flow of 904,105 lb/hr or 1,807 gpm is also needed.

Finally, the scaled reprocessing plant contains approximately 2,600 horsepower identified in various items. To this was added additional demands for centrifuges, conveyors, clarifier rakes, etc., not included in the RCC report, in the amount of 865 horsepower for a total of 3,465 horsepower. This represents a demand of 2.58 MW from the MHD plant electrical output.

The above scaling factors and utility requirements have been used in the cost and the MHD plant efficiency calculations.

2.4 PROCESS MASS AND ENERGY BALANCE

2.4.1 Process Mass Balance

The MHD plant will put out 27,889 lb/hr of spent seed from the HR/SR and ESP units. Of this, 16,821 lb/hr will be directly recycled to the MHD combustor. This will provide all the K_2SO_4 needed for plasma conductivity purposes. It will also provide 217 lb/hr of the 8,209 lb/hr of K_2CO_3 needed for sulfur control. Thus, 7,992 lb/hr of K_2CO_3 must be obtained from the seed processing plant.

The 11,068 lb/hr of spent seed remaining after direct recycle constitutes the primary input for reprocessing. Other inputs required are 3,749 lb/hr of CaO, 79 lb/hr of MgO, 2,033 lb/hr of 36 wt. percent HCl, 1,138 lb/hr of KCl, and 3,412 lb/hr of CO_2 derived from MHD flue gas.

The primary output of the reprocessing plant is the 7,992 lb/hr of K_2CO_3 required. There are also two waste streams totaling 24,772 lb/hr. An insolubles waste stream of 22,208 lb/hr contains 8,596 lb/hr of gypsum ($CaSO_4$ $2H_2O$), 1,624 lb/hr of $CaCO_3$, 741 lb/hr of insolubles, 101 lb/hr of $Mg(OH)_2$, 28 lb/hr of Engel salt ($KHCO_3 \cdot MgCO_3 \cdot 4H_2O$), and 11,118 lb/hr of H_2O. A solubles waste stream of 2,564 lb/hr contains 1,769 lb/hr of NaCl, 148 lb/hr of $CaCl_2$, 8 lb/hr of $MgCl_2$, and 639 lb/hr of H_2O.

The reprocessing plant uses 903,000 lb/hr of 1,807 gpm of cooling water.

The 6,706 lb/hr of process water needed is supplied by the water in the HCl solution, Stream 34, the booster steam in Stream 30, and the condensate from Streams 48 and 49. Other water needs are supplied by internal generation and recirculation. In fact, the water balance is slightly positive with more water into the reprocessing plant than out. However, several vents have not been considered, nor has a leakage account been taken. Hence, the water balance can be considered closed.

Details of the above are contained in Figures 2-4 through 2-10 and Table 2-2. Figures 2-4 through 2-10 have been taken from the RCC Task #2 Report, but have been renumbered, since consideration has been given in the scaling only to those streams crossing module boundaries. This resulted in elimination of some internal streams and addition of streams from vents, etc.

2.4.2 Process Energy Balance

The ETF design was modified where necessary in order to accommodate the energy requirements of the scaled RCC process. All heat balance calculations were restricted to the interface between the Engel-Precht Process and the bottoming cycle of the MHD-ETF system. These are described in Section 3.3. As shown in Attachment A, the heat balance performed by RCC used an overall approach. A heat and material balance over each item of equipment should be carried out during any detailed design phase which may be initiated at a later date.

2.5 PROCESS ECONOMICS FOR ON-SITE REGENERATION

2.5.1 Capital Costs

Capacity modifications to the Engel-Precht Process were made as described in Section 2.3. The results, which are in the form of the material balance shown in Table 2-2, were obtained by applying scaling factors to the RCC 450 MWt Rosebud Coal Case. With few exceptions, the same scaling factors were applied to the equipment costs listed by RCC for the 450 MWt Rosebud Coal Case. The resulting total plant investment, which is shown in Table 2-3, is based on the following assumptions:

1. All costs in the estimate are based on present day costs (1st quarter, 1981) to coincide with the MHD-ETF cost summary.

2. All major equipment, less the rotary dryer, were extrapolated from the RCC 450 MWt Rosebud Coal Case. Each item was resized to correspond to a spent seed rate of 11,068 lb/hr, and then exponentially costed and escalated one year for each specific major component.

3. Cost for the rotary dryer is a vendor budget cost with installation cost provided by in-house erection data.

4. Balance of Account (BOA) costs are taken as 30 percent of the major components cost. This is the same percentage used in the MHD-ETF boiler plant cost estimate. These costs include bulk materials, e.g., piping, cable, wiring, instrumentation, valving, and others.

5. Installation costs are 67 percent of major components and BOA as shown in the above mentioned case.

6. Indirect costs are 70 percent of installation labor and represent constructor's home office project support, field supervision, field office, temporary facilities, small tools, consumables, construction equipment, etc.

7. Engineering costs for professional services are 8 percent of total direct and indirect costs less contingency.

8. Other costs are an allowance of 2.5 percent of the sum of the direct, indirect, and professional services for government field staff and owner's legal fees.

9. Contingency is 20 percent of total plant cost because there is a high risk due to the developmental nature of the process.

With the exception of item 5, these assumptions are the same as those used in the MHD-ETF CDER Cost Summary. Item 5 was based upon the MHD Commecial Plant Study.

FOLDOUT FRAME

	K_2CO_3	K_2SO_4	Na_2CO_3	KCl	NaCl	$CaCl_2$	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	Insol.	Engel Salt	$MgCO_3 \cdot 3H_2O$
1. from MHD	360	21648	4038						1843		
2. recycle	217	13067	2435						1102		
3. to regeneration	143	8581	1603						741		
4.				5102		7345					
5.				1218	693		510				
6.				23		74				33	161
7.				13770	2462	148	510				
8. wash in											
9. filter cake out							8596	1624	741	28	
10. 21.6 psig steam in											
11.											
12. 21.6 psig steam in											
13. cooling water											
14.											
15. to wash											
16. wash in											
17.					1769	148					
18.				12552							
19. 100 psig steam in											
20. cooling water											
21. wash in											
22.											
23. cooling water											
24.				5125							
25.											
26.											
27. KCI makeup				1138							
28. cooling water											
29. to wash											
30. 100 psig steam in											
31. cooling water											
32.											
33.											9427
34.											
35. air											
36.											
37.				5125							

ENGEL-PRECHT PROCESS MASS BALANCE

Engel Salt	$MgCO_3 \cdot 3H_2O$	$MgCl_2$	$Mg(HCO_3)_2$	$Mg(OH)_2$	CaO	MgO	CO_2	HCl	$KHCO_3$	Inerts	Air	Steam	$H_2O(l)$	Solids	TOTAL		
														27889	27889		
														16821	16821		
														11068	11068		
													74331	12447	86778		
													3737	2421	6158		
33	161			40									799	331	1130		
													81233	16890	98123		
													3860		3860		
28				101									11090	11090	22180		
												967			967		
												1294			1294		
												3878			3878		
													309784		309784		
													317907		317907		
													66896		66896		
													715		715		
		8											639	1925	2564		
													4184	12552	16736		
												330			330		
													12710		12710		
													14119		14119		
													13315		13315		
													15128		15128		
		5465	1385										67728	11975	79703		
							2943					5183		2943	8126		
							2943					503		2943	3446		
														1138	1138		
													455545		455545		
													11859		11859		
												5405			5405		
													110938		110938		
													21234		21234	*	
	9427												34131	9427	43578		
								732					1301	732	2033		
											1861				1861		
							1140				1861			1140	3001		
		6366											69105	11491	80596		

FOLDOUT FRAME

	K_2CO_3	K_2SO_4	Na_2CO_3	KCl	NaCl	$CaCl_2$	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	Insol.	Engel Salt	$MgCO_3 \cdot 3H_2O$
38.											
39. wash in											
40.											
41. flue gas											
42.											
43.				3							
44. to wash											
45. flue gas											
46.											
47. excess steam											
48. 60 psig steam in											
49. 60 psig steam in											
50.	7992			3							
51.	7992			3							
52. to MHD	8209	13067	2435	3					1102		
53. flue gas to dryer											
54. to scrubber											
55.											
56. wash in											
57. condensate out											
58. condensate out											
59. condensate out											

* 15,130 lb/hr
6,104 lb/hr

FOLDOUT FRAME

PROCESS MASS BALANCE

Page 2 of 2

$_2$	$Mg(HCO_3)_2$	$Mg(OH)_2$	CaO	MgO	CO_2	HCl	$KHCO_3$	Inerts	Air	Steam	$H_2O(l)$	Solids	TOTAL		
			3749	79								3828	3828		
											43718		43718		
		3974									36745	3974	40719		
					7495			14376		2142		24013	24013		
					4514			14376		2142		21032	21032		
3							11579				75880	11585	87465		
											62918		62918		
					1036			1987		296		3319	3319		
					621			1987		296		2904	2904		
											5149		5149		
										11876			11876		
										3254			3254		
3											2645	7998	10643		
3												7998	7998		
3												24819	24819		
					25837			49554		4889		80280	80280		
					25837			49554		7534		82925	82925		
											115736		115736		
											72341		72341		
											3878		3878		
											11876		11876		
											3254		3254		

om blowdowns and
m internal condensate.

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TABLE 2-3

ON-SITE ENGEL-PRECHT PROCESS CAPITAL COST

Materials		
Major Components	$	5,346,000
BOA		1,550,000
Subtotal	$	6,896,000
Erection		
Labor Installation		4,620,000
Total Direct Cost	$	11,516,000
Indirects		3,234,000
Subtotal	$	14,750,000
Engineering		1,180,000
Other Costs		398,000
Total Plant Cost	$	16,328,000
Contingency		3,266.000
Total Plant Investment (1/81)	$	19,594,000

The following items are not included in the estimate:

- Interest during construction
- Sales and use taxes
- Capital spare parts
- Scheduled overtime
- Escalation

2.5.2 Operating and Maintenance (O&M) Costs

O & M costs, excluding fixed capital charges, are estimated in Table 2-4, and the basis for each unit cost is listed in Table 2-5. Chemical costs in Table 2-5 were taken from the Chemical Marketing Reporter. Utility and labor costs are based on current Gilbert in-house costing data.

2.5.3 Product Cost

Fixes Charges

Assuming the same fixed charge rate and capacity factor as was used in the MHD ETF CDER, 0.22 per year, and 65 percent (5,698 hr/yr) the fixed charges for producing 7,992 lb/hr of K_2CO_3 on-site were estimated as follows:

$$\frac{0.22 \times 19,594,000 \times 100}{7,992 \times 5,698} = 9.47\ ¢/lb$$

Operating and Maintenance

Based on the annual net operating and maintenance cost shown in Table 2-4, the corresponding cost in cents per pound of K_2CO_3 produced was estimated as follows:

$$\frac{4,382,000 \times 100}{7,992 \times 5,698} = 9.62\ ¢/lb$$

Product Cost Estimate

Based on the assumption that spent seed is available to the Engel-Precht Process at no cost, the cost of the product will be 9.47 + 9.62 = 19.1 ¢/lb.

The current 1981 cost of K_2CO_3 on the open market is 26.3 ¢/lb ($325/ton). The market value of K_2SO_4 is approximately 5¢/lb ($100/ton). Based on the assumption that the spent seed is worth 2.5¢/lb, it follows that the cost of shipping the seed chemicals on and off site is 23.8 ¢/lb.

TABLE 2-4

ANNUAL OPERATING AND MAINTENANCE COSTS, ON-SITE SEED REPROCESSING

Plant Capacity: 11,000 lb/hr Spent Seed
Annual Availability: 5,698 hrs/yr

	Consumption		Unit Cost	Annual Cost
	Daily	Annual	$ ('81)	MM$
Raw Materials				
Lime, ton	45	10,684	45	0.481
Potassium Chloride, ton	14	3,324	65	0.216
Magnesia, ton	0.95	226	55	0.012
Hydrochloric Acid (36%), ton	24.4	5,793	78	0.452
Freight, ton, ST/mi	-	20,026	0.07[a]	0.420
Utilities				
Power, KWh	62,040	14.7×10^6	0.036	0.529
Cooling Water, gals	2,601.744	617.7×10^6	0.00015	0.093
Steam, lb/hr				
60 psig	363,120	86.2×10^6	0.0073	0.629
100 psig	137,640	32.7×10^6	0.0073	0.239
O&M				
Operating Personnel, hrs.	96	35,040	17.00	0.596
Supervision	-	-	20% Op. Labor	0.119
Maintenance	-	-	4.0% TDC	0.461
Insurance & Taxes Allowance	-	-	1.0% TPI	0.196
Waste Disposal				
Gypsum and Flyash, ton	266.6	63,296	3	0.190
GROSS OPERATING, MM$/yr.				4.633
By-Product Credits				
Sodium Chloride, ton	21.2	5,033	50	(0.251)
NET OPERATING, MM$/yr.				4,382

[a] Distance, miles 300

TABLE 2-5

BASIS FOR ON-SITE OPERATION COSTS[a]

Lime	$45/ton
Potassium Chloride	$65/ton
Magnesia	$55 /ton
Hydrochloric acid (36%)	$78/ton
Electricity	$0.036/kWh
Industrial Cooling Water	$0.15/1,000 gal.
Steam @ 100 psig, °F	$7.30/1,000 lb.
Steam @ 60 psig, °F	$7.30/1,000 lb.
Operating labor (incl. fringe & overhead)	$17.00/hr
Supervision	20% of labor
Maintenance (Mat'l + labor)	4% of capital/year
By-products	
Waste disposal cost	$3.00/ton
Sodium chloride credit	$50/ton

(a) These operating costs are based on data from the Chemical Marketing Reporter and current Gilbert in-house costing data as of 1st quarter 1981.

2.6 PROCESS ECONOMICS FOR OFF-SITE REGENERATION

The stand alone regeneration plant would have to supply its own utilities including:

100 psig steam	5,735 lb/hr
60 psig steam	15,130 lb/hr
Cooling Water	903,000 lb/hr
	1,807 gpm
Boiler feed water makeup	21,000 lb/hr
	42 gpm
Carbon dioxide	3,400 lb/hr
Power	2.58 MW

The additional equipment needed for the stand alone plant is a small, oil fired package boiler, including feed water treatment, a cooling water recirculation and heat rejection system, a CO_2 supply system, and storage silos with associated conveyors.

Since there is not enough CO_2 in the boiler flue gas to supply the plant, a separate CO_2 storage and supply system was assumed. It was also assumed that the power needed was purchased from the grid.

The capital costs of the package boiler and the cooling tower replace the operating costs for steam and cooling water. However, additional operating costs are picked up for fuel oil and for carbon dioxide.

Using the same assumptions as in Section 2.5, the total plant investment, including the additional equipment, is tabulated in Table 2-6. The O & M costs and basis are tabulated in Tables 2-7 and 2-8.

The product cost for off-site regeneration was estimated in the same manner as for on site regeneration.

$$\text{Fixed Charges} = \frac{0.22 \times 22{,}500{,}000 \times 100}{7{,}992 \times 5{,}698} = 10.87 \text{ ¢/lb}$$

$$\text{Operating and Maintencance} = \frac{5{,}447{,}000 \times 100}{7{,}992 \times 5{,}698} = 11.96 \text{ ¢/lb}$$

$$\text{Spent Seed Cost} = \frac{11{,}068 \times 2.5}{7{,}992} = 3.46 \text{ ¢/lb } K_2CO_3 \text{ produced}$$

$$\text{Total Product Cost} = 10.87 + 11.96 + 3.46 = 26.3 \text{ ¢/lb}$$

The current cost of K_2CO_3, if purchased in the open market, is approximately 26.3 ¢/lb ($525/ton).

TABLE 2-6

OFF-SITE ENGEL-PRECHT PROCESS CAPITAL COST(a)

	On-site	Additional Capital for Off-Site
Materials		
Major Components	$ 5,346,000	$ 1,000,000
BOA	1,550,000	550,000
Subtotal	$ 6,896,000	$ 1,550,000
Erection		
Labor Installation	4,620,000	370,000
Total Direct Cost (TDC)	$ 11,516,000	$ 1,920,000
Indirects	3,234,000	260,000
Subtotal	$ 14,750,000	$ 2,180,000
Engineering	1,180,000	170,000
Other Costs	398,000	60,000
Total Plant Cost	$ 16,328,000	$ 2,410,000
Contingency	3,266,000	490,000
Total Plant Investment (TPI) (1/81)	$ 19,594,000	$ 2,900,000
Total Off-Site Plant Investment	$ 22,494,000	

(a) These on-site major components costs are based primarily upon scaled up RCC data. Additional capital costs are estimated by Gilbert.

TABLE 2-7

ANNUAL OPERATING AND MAINTENANCE COST, OFF-SITE SEED REPROCESSING

Plant Capacity: 11,000 lb/hr Spent Seed
Annual Availability: 5,698 hrs/yr

	Consumption		Unit Cost	Annual Cost
	Daily	Annual	$ (81)	MM$
Raw Materials				
Lime, ton	45	10,684	45	0.481
Potassium Chloride, ton	14	3,324	65	0.216
Magnesia, ton	0.95	226	55	0.012
Hydrochloric Acid (36%), ton	24.4	5,793	78	0.452
Carbon Dioxide	41	9,722	71	0.690
Freight, T, T/mi	-	20,026	0.07[a]	0.420
Utilities				
Power, Wh	62,040	14.7×10^6	0.036	0.529
Fuel Oil, gal	5,863	1.39×10^6	0.81	1.128
O&M				
Operating Personnel, hrs.	120	43,800	17.00	0.745
Supervision	-	-	20% Op. Labor	0.149
Maintenance	-	-	4.0% TDC	0.461
Insurance & Taxes Allowance	-	-	1.0% TPI	0.225
Waste Disposal				
Gypsum and Flyash, ton	266.6	63,296	3	0.190
GROSS OPERATING, MM$/yr.				5.698
By-Product Credits				
Sodium Chloride, ton	21.2	5,033	50	(0.251)
NET OPERATING, MM$/yr.				5.447

[a]Distance, 300 miles

TABLE 2-8

BASIS FOR OFF-SITE OPERATING COSTS(a)

Lime	\$45/ton
Potassium Chloride	\$65/ton
Magnesia	\$55/ton
Hydrochloric acid (36%)	\$78/ton
Carbon Dioxide	\$71/ton
Electricity	\$ 0.036/kWh
Fuel Oil	\$ 0.81/gal
Operating labor (incl. fringe & OHD)	\$17.00/hr
Supervision	20% of labor
Maintenance (Mat'l + labor)	4% of capital/year
By-products	
Waste disposal cost	\$3.00/ton
Sodium chloride credit	\$50/ton

(a) These operating costs are based on data from the Chemical Marketing Reporter and current Gilbert in-house costing data.

3.0 PROCESS INTEGRATION

3.1 SYSTEM INTEGRATION CRITERIA

The ETF system heat and material balance, as shown on Drawing No. 8270-1-540-314-001, was based on a once-through calculation. Recycling increases the more volatile constituents of the fresh ash, and the different chemical composition of the reprocessed seed stream will further change the state points along the flow path through the channel and HR/SR. Some changes in the topping cycle state points (from the once-through case) will occur, but the changes are expected to be small by comparison with uncertainties caused by lack of general agreement on the chemical composition of the condensed species. For this reason a rigorous evaluation on the impact of reprocessed seed on the topping cycle was not conducted; and, without a rigorous evaluation of the topping cycle, it was decided that it would be inappropriate to generate a new heat and mass balance diagram of the ETF cycle for the integrated case. This study was limited to the assessment of the cost and technical impact of ETF/Engel-Precht integration by making the maximum use of studies already reported in the MHD-ETF CDER and the RCC Task #2 Report.

Although no overall heat and mass balance diagram was generated, the steam cycle was rebalanced, and the flue gas distribution downstream of the heat recovery equipment was revised to reflect the on-site reprocessing requirements.

3.2 INTEGRATED SYSTEM DESCRIPTION

3.2.1 Systems Analysis

3.2.1.1 Summary of Process Requirements

Based on the process mass balance the process requirements to regenerate spent seed are as follows:

Electrical Power	2,585 kW
Steam	5,735 lbm/hr dry saturated at 100 psig
	15,130 lbm/hr dry saturated at 60 psig
Flue Gas for CO_2	8,531 lbm/hr CO_2 (27,331 lbm/hr flue gas at 228^{o}F stack temperature
Flue Gas for Seed Drying	80,280 lbm/hr at 480.9^{o}F
Cooling Tower Heat Rejection	22.6 x 10^6 Btu/hr

3.2.1.2 Procedure

ETF plant performance was analytically evaluated using the GAI PROTEUS computer code. Seed reprocessing process requirements for electrical power, steam, flue gas, and heat rejection were integrated into the current ETF configuration to evaluate the plant efficiency impact. For the integrated on-site seed reprocessing cycle, the MHD combustor would be seeded with reprocessed seed. The composition and flow rate of the seed stream in this case is somewhat different than for the current ETF cycle. For this study the impact that reprocessed seed stream composition and flow rate would have on the gas path performance were assumed to be negligible. Performance evaluation of the ETF cycle with integrated seed reprocessing was limited to modifications to the steam cycle, auxiliary power, and flue gas distribution.

3.2.1.3 Discussion

The MHD ETF cycle computer analyses carried out to date assumed once-through seed flow with off-site reprocessing of spent seed. Figure 2-1 shows the solids flow diagram for the Conceptual Design Engineering Report (CDER) configuration. For the current study, on-site reprocessed seed was to be used. The solids flow diagram for this configuration is shown on Figure 2-2. The solids flows in these figures are essentially the same as the solids flows for the once-through case, except for an added ash flow of 3,537 lbm/hr which was included in the reprocessed seed sent to the MHD combustor. The additional ash flow was considered negligible and all design parameters for the topping cycle were assumed to remain unchanged. Actually, this additional ash flow would increase flue gas flow 0.34 percent. Studies on the impact of the added ash flow on combustor performance have indicated that flame temperature and conductivity decrease by 15°F and 4.6 percent, respectively. The flame temperature decrease is not large but the 4.6 percent decrease in conductivity is more than a negligible change. However, compensating any loss in MHD channel power due to reduced conductivity is the increase in both channel and steam turbine power that would be generated by the increased flue gas flow produced by the higher seed flow rate. Considering the scope of work for this task the assumption that the added ash flow will not impact the topping cycle operating characteristics seems to be appropriate. The seed reprocessing integration analysis, therefore, concentrated on the modification of the steam cycle and flue gas flow distribution to meet the seed reprocessing requirements. These requirements were integrated into the ETF cycle as follows:

1. Electrical

   To meet the electrical power needs, the plant auxiliary power requirements were increased the appropriate amount.

2. Steam

   The seed reprocessing system requires 5,735 lbm/hr of dry saturated steam at 113 psia (100 psig) as well as 15,130 lbm/hr of dry saturated steam at 73 psia (60 psig). To provide this dry saturated steam for seed reprocessing the steam turbine generator set was reconfigured slightly from the CDER design as shown in Figure 3-3. The unit remained a tandem compound reheat type steam turbine with 1,815 psia/1,000°F throttle

conditions with a 1,000°F reheat. However, the low pressure turbine crossover steam pressure was increased from the 58.6 psia used in the CDER design to 80.8 psia. This provided a more accessible steam turbine extraction point to supply the 73 psia steam flow for seed reprocessing. To meet the 113 psia steam flow requirement, another steam extraction point at 129.5 psia was added to the reheat steam turbine section. These steam turbine modifications are consistent with standard steam turbine practice and would not require a custom turbine design. The extraction pressures account for the anticipated steam line and desuperheater pressure drops that would be expected in the steam supplied to the seed reprocessing site.

The two steam extractions required to meet the seed reprocessing flow requirements are each superheated, therefore, desuperheaters are required to reduce the steam to dry saturated conditions. Feedwater extraction after the steam cycle booster pump was selected for desuperheating the extracted superheated steam. Feedwater pressure at this point was 250 psia which was sufficient to allow for line pressure drop to the desuperheater while providing adequate pressure drop in the desuperheater spray nozzle. Total feedwater extraction to desuperheat both steam streams was 2,979 lbm/hr or 0.28 percent of the feedwater flow. The 129.5 psia steam extraction was 4,794 lbm/hr, to which 941 lbm/hr as feedwater spray was used to desuperheat the steam for the 113 psia delivery. The 80.8 psia crossover point supplied 13,092 lbm/hr steam to which 2,038 lbm/hr of spray was added to supply the 73 psia delivery.

3. Flue Gas for CO_2

The flue gas extracted as a CO_2 source for process use was drawn from the duct leading to the stack. Seed reprocessing needs CO_2 at 150°F and 16 psia, and flue gas at the stack was the coolest source in the plant (231°F). After allowing for temperature rise in the compressor the temperature of this flue gas reached 280°F. An aftercooler to bring the flue gas to the 150°F temperature requirement was needed. Considering the flue gas flow rate involved (27,331 lbm/hr) to supply the required CO_2 (8,531 lbm/hr) an air aftercooler was assumed.

4. Flue Gas for Seed Drying

Flue gas for reprocessed seed drying was drawn from the main flue gas stream between the electrostatic precipitator and low temperature economizer. This extraction is similar to flue gas extractions required for other ETF process and heating needs. The 80,280 lbm/hr of flue gas required for seed drying was based on dryer design requirements established by the dryer manufacturer and assumptions made in Section 2.1.3 regarding the water in the wet reprocessed seed. The dryer manufacturer indicated a 75°F temperature approach should be maintained between the flue gas and the seed. The process required that the seed enter the dryer at 275°F and leave at the highest temperature the equipment allows (423°F). Therefore, enough heat was required in the dryer to evaporate the surface moisture and raise it to the dryer flue gas exit temperature (350°F).

A fan, which required additional auxiliary power, was added to pass the dryer flue gas to the seed dryer. The main flue gas induced draft fan provided the power required to pass the dryer exhaust to the main stack. A baghouse was included in dryer exhaust stream to remove any seed elutriated in the dryer. The seed dryer is a rotary type and a small driving motor was included in the process auxiliary power.

5. Cooling Tower Heat Rejection

Circulating water through the cooling tower was increased to accommodate the heat rejection rates for seed reprocessing. As a result circulating water pump power and cooling tower fan power were increased proportionally by the increased circulating water flow rate and increased heat rejection load.

3.2.2 Layout

3.2.2.1 Plot Plan

Integrating the seed regeneration equipment into the existing MHD-ETF plant will require careful study for the optimization of the necessary utilities. There is sufficient space available for the seed regeneration facility. The major structures to be added are the seed regeneration building, two large diameter clarifiers, and a dryer building. The seed regeneration system will require integration with existing equipment such as storage silos, hoppers, and conveyors. All other new equipment, not in the above, will be located in the existing coal seed feed building.

Figure 3-1, Plot Plan, is a small section of Drawing No. 8270-1-210-007-001, Plot Plan. It shows the suggested location of the seed regeneration building, the clarifiers and the dryer building in cross-hatch.

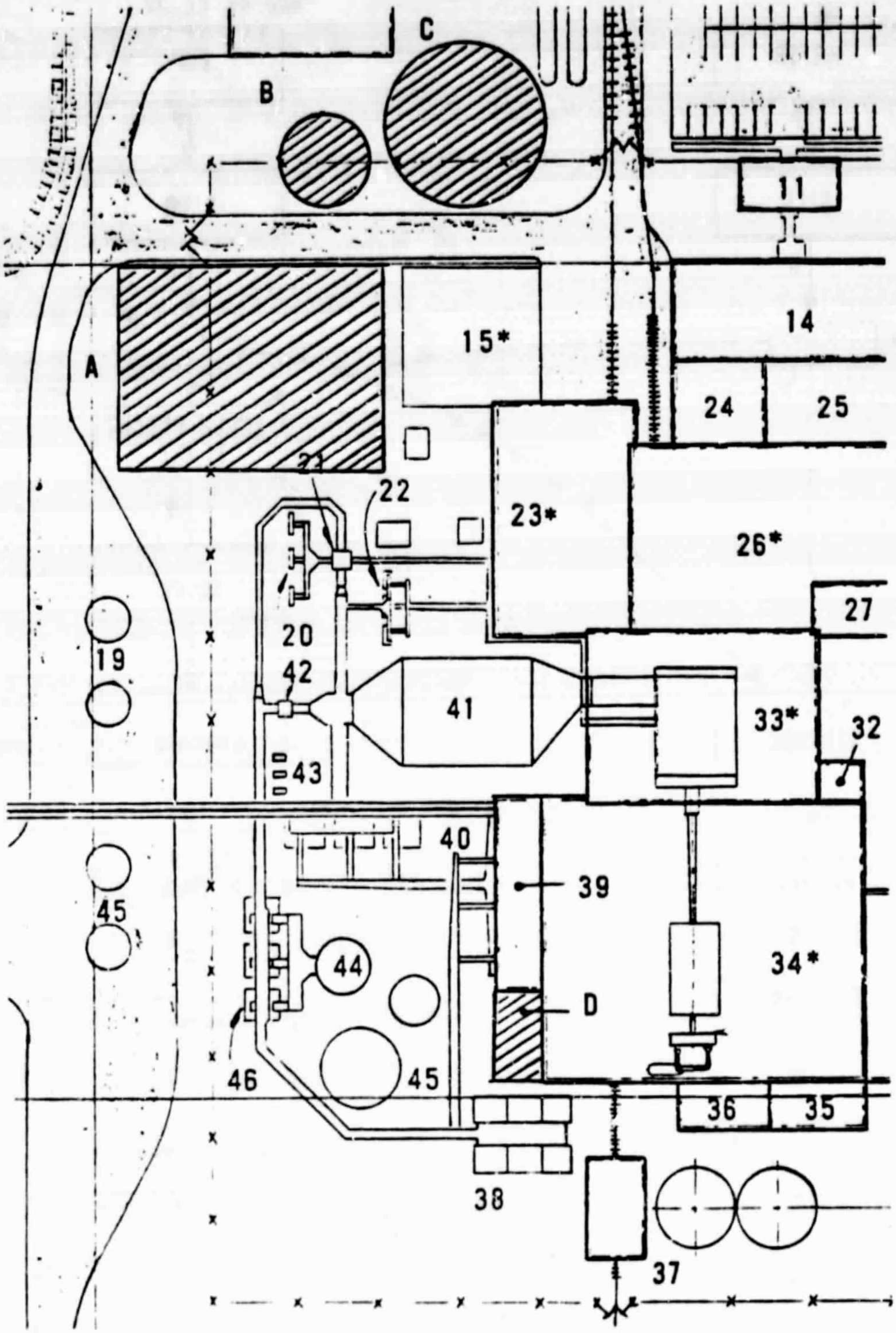
3.2.2.2 Materials Handling Systems

As shown in Figure 3-2, seed processing begins with the recovery of spent seed in the convective section of the HR/SR and in the ESP. The spent seed at these two points is a mixture primarily of K_2SO_4 and fly ash.

As the gas stream passes through the HR/SR it changes direction in the convective section and in so doing the spent seed falls by gravity into hoppers below. The spent seed in the hoppers is conveyed by a pneumatic system to a spent seed storage silo.

The gas stream continues on to the ESP where most of the remaining spent seed and fly ash are removed by the action of an electrostatic field. The spent seed and fly ash are shaken down into hoppers below the ESP. From the hoppers, the spent seed is again conveyed by a pneumatic system to a second spent seed storage silo.

For startup and test purposes, new seed will arrive in sealed railroad cars, 100 ton maximum capacity. The seed is dumped into covered mechanical conveyors which deliver it to the K_2SO_4 and K_2CO_3 storage silos. The K_2CO_3 is covered at all times to prevent moisture pickup from the atmosphere.



A ENGEL-PRECHT PROCESS EQUIPMENT BUILDING
B GYPSUM THICKENER
C MAGNESIUM HYDROXIDE CLARIFIER
D POTASSIUM CARBONATE DRYER
19 SPENT SEED AND FLY ASH SILOS
35 SEED FEED BUILDING
37 SEED UNLOADING FACILITY

FIGURE 3-1
EQUIPMENT LAYOUT - PLOT PLAN

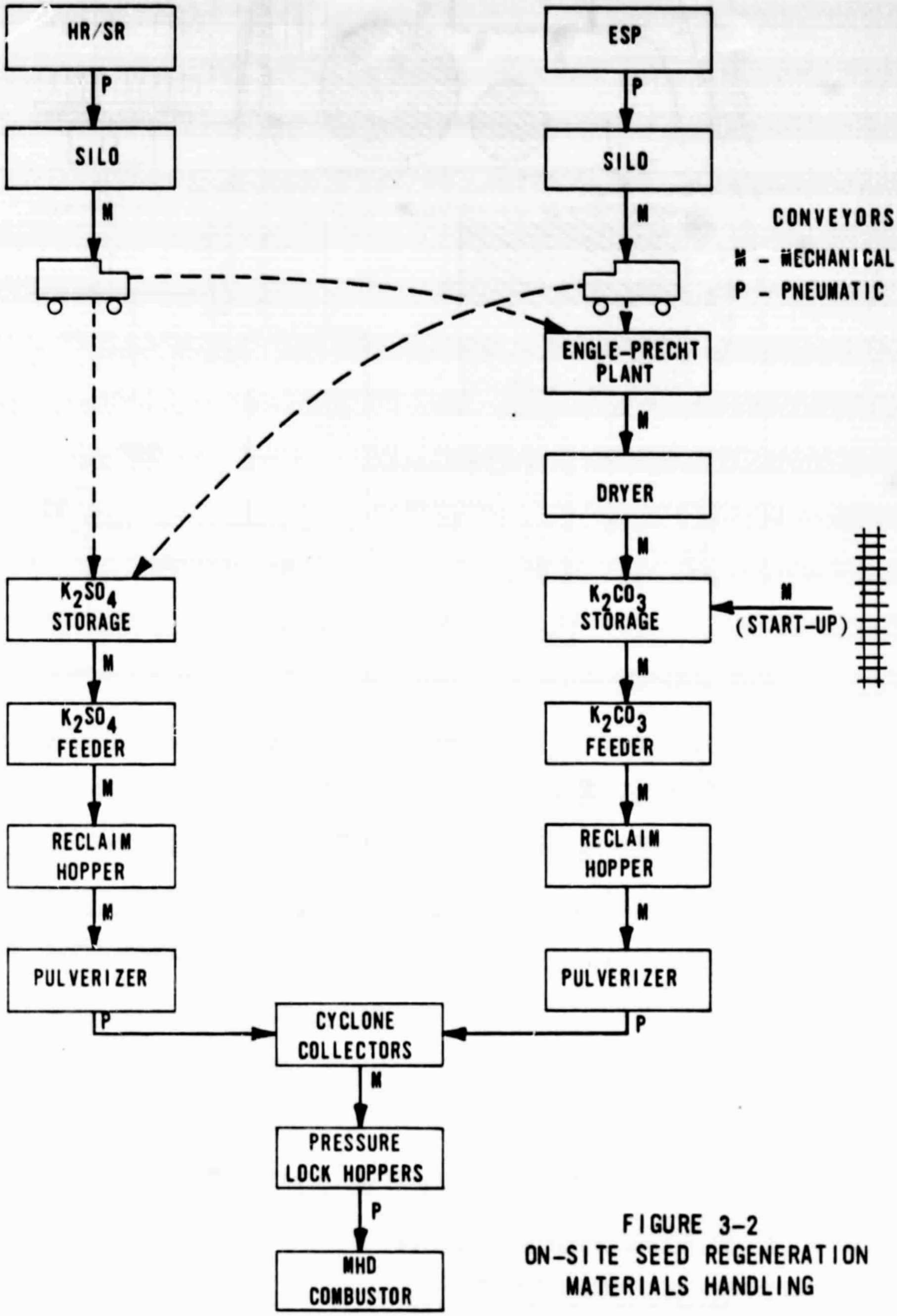


FIGURE 3-2
ON-SITE SEED REGENERATION
MATERIALS HANDLING

Under normal operating conditions, spent seed, which is mostly K_2SO_4, is carried by truck from the spent seed silos to the K_2SO_4 storage silo where it is unloaded using the facilities provided for unloading the railroad cars containing fresh K_2SO_4. Under normal operating conditions, wet K_2CO_3 from the seed reprocessing plant is mechanically conveyed to the K_2CO_3 dryer and then mechanically conveyed in a closed conveyor system to the K_2CO_3 storage silo.

The K_2CO_3 and K_2SO_4 storage silos and related equipment have been used in the same way as described in the MHD-ETF CDER for two reasons. First, the ETF is a test facility, consequently greater operational flexibility is achieved by using truck transportation for the K_2SO_4 and by retaining the large K_2SO_4 and K_2CO_3 storage silos within the K_2SO_4 and K_2CO_3 recycle loops. Second, it is a design requirement for this study that the RCC Modified Engel-Precht Seed Reprocessing System shall use the storage silos and related equipment as described in SDD-342.

When K_2CO_3 or K_2SO_4 is required from a storage silo, a mechanical conveying system carries the appropriate amount of material to the seed preparation area.

The seed preparation area is combined with coal preparation near the coal preparation building. All solid seed streams are weighed and flow measured in feeders, seed for the K_2SO_4 feeder and regenerated seed for the K_2CO_3 feeder. The individual streams are fed into separate reclaim hoppers. From each reclaim hopper the seed is fed to separate pulverizers and finely ground. The powdered seed is then pneumatically conveyed to a mechanical cyclone collector. The proper ratio of the two seeds is fed to and intimately mixed in the cyclone collector. The mixture of seed is measured continuously by noting the total weight of the cyclone collector.

From the cyclone collector the seed mixture is fed to the pressurized seed lock hopper system and then to the MHD combustor.

The seed regeneration plant receives steam, cooling water and hot flue gas from the MHD-ETF cycle and utilizes these in the chemical process. Other chemicals required are brought in by truck.

3.3 SYSTEM HEAT AND MASS FLOW

An overall heat and material balance for the integrated system is shown in Figure 3-3.

Flue gas from the MHD-ETF is used as a source of carbon dioxide (CO_2) in the the Engel-Precht Process. It is tapped off the main flue gas stream after the induced draft fans at 231°F. The temperature is too high for use in the process directly so it is passed through a gas to air heat exchanger to reduce the temperature to the required 150°F.

Flue gas is also used as a source of heat to dry the product from the Engel-Precht Process. High temperature flue gas is tapped off the main stream after the ESP at 481°F. A booster fan moves the gas through a rotary dryer mixing it with wet seed from the process. The seed is tumbled and mixed with the hot gas driving off surface moisture and bound moisture.

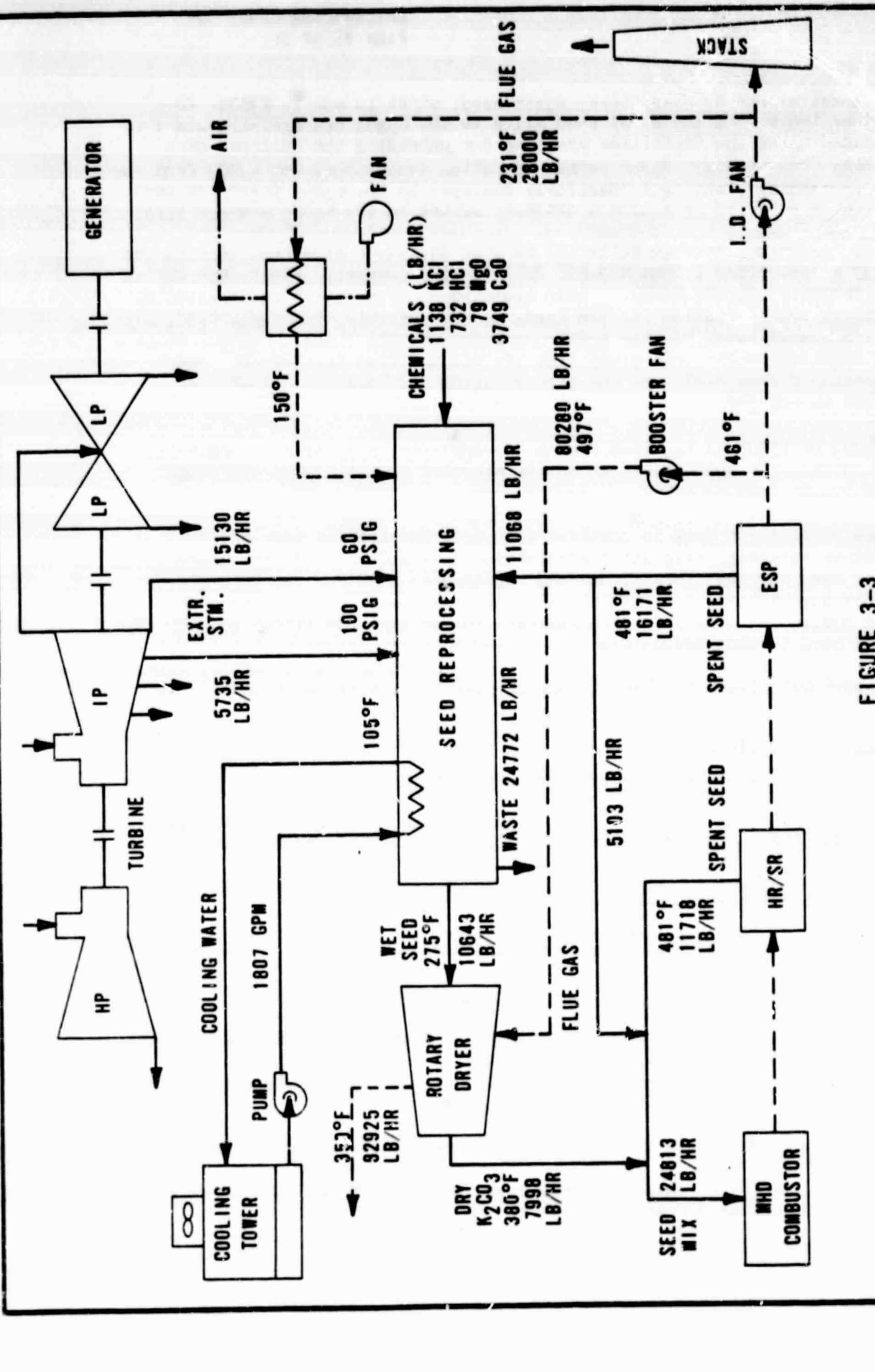


FIGURE 3-3
ON-SITE SEED REPROCESSING MATERIAL BALANCE

The Engel-Precht seed reprocessing system requires steam which it uses in several ways, such as to evaporate water from a chemical product or create a vacuum in a process containment vessel by means of an eductor. The Engel-Precht Process utilizes two steam conditions - 100 psig and 60 psig dry and saturated.

When operating in conjunction with the MHD-ETF plant all the utilities will be supplied by the Topping and Bottoming Cycles - the electricity, the cooling water, the heat and CO_2 from the flue gas and the steam. This steam is normally extracted from two points on the main steam turbine.

To back-up the extraction steam supply from the main turbine (should there be any malfunction, or if the plant is down) the Auxiliary Steam System (SDD-051) can be relied upon to take over this function.

The Auxliary Steam System has sufficient capacity to handle the flows required by the Engel-Precht Process. The boilers are nominally rated at 100 psig, 350°F whic is slightly superheated. The 60 psig steam is obtained by pressure reduction of the 100 psig steam, and if there is any objections to the slight amount of superheat, spray water can be added in a de-superheating station which will take care of this condition.

In either case, using the extraction steam from the main steam turbine or obtaining the steam from the Auxiliary Steam System, the make-up water requirements to replace the approximately 21,000 lb/hr of steam will be the same.

An external cooling water source is required and is supplied from the circulating water system, cooling tower complex.

Raw materials for the Engel-Precht Process are spent seed, flue gas (CO_2), steam and various chemicals. The end product is reprocessed seed (wet K_2CO_3) and waste products such as minerals and flue gas depleted of CO_2.

3.4 ETF IMPACTS

3.4.1 Impact on Plant Efficiency

Integrating the seed reprocessing unit into the ETF cycle reduced the steam turbine generator power produced because of the new steam extractions for process use and because of the increased steam extraction required for feedwater heating. The increased feedwater heating was required to offset heating that previously was done by the flue gas in the economizer in the CDER design. In the integrated system, this flue gas is now extracted for reprocessed seed drying. In addition, auxiliary power was increased to meet the electrical requirements of the process equipment and to supply the power requirements of the necessary support systems, such as added cooling tower power requirements because of heat rejection due to process influence, and feedwater power requirements necessary to supply the additional water for the steam extractions for process use. The net result was that plant gross power decreased and auxiliary power increased. Net power output decreased 4.7 MWe for constant heat input (coal flow). Table 3-1 summarizes the plant

TABLE 3-1

ETF PERFORMANCE SUMMARY FOR INTEGRATED

ON-SITE SEED REPROCESSING CYCLE

Seed Reprocessing included	Yes	No (CDER Design)
Gross Power, kW	213,192	215,130
Auxiliaries, kW	15,556	12,780
Net Power, kW	197,636	202,350
Coal Heat Input, kWt	531,974	531,974
Plant Efficiency, %	37.15	38.03
Plant Heat Rate, Btu/kWh	9,165	8,972

performance for the ETF cycle with and without on-site seed reprocessing. As can be readily seen on Table 3-1, the integration of seed reprocessing into the ETF cycle will produce nearly an 0.9 point drop in plant efficiency and nearly a 5 MW decrease in net power output. However, these impacts are offset by an operating expense savings of not buying fresh seed which results in a small decrease in the cost of electricity.

3.4.2 Impact on Equipment

Adding a seed reprocessing unit to the site will result in more equipment, structures, conveyors, piping and duct work which will raise the total cost of the MHD-ETF. Adding equipment will also add to the complexity of operating the plant. On the other hand better control can be exercised over seed management and seed quality.

In order to integrate the seed regeneration plant with the present ETF design a few additions and resizing of existing equipment must be done. The major changes include:

- o Increasing the size of the cooling tower by 2.0 percent to provide cooling water to the seed regeneration plant.
- o Increasing the plant makeup water system by 2.0 percent since the seed regeneration plant's condensate will be used as makeup process water.
- o Extending two steam lines approximately 500 feet each from the turbine building to the reprocessing plant to provide process steam.
- o Addition of a 600 feet belt conveyor to transport the wet seed to the dryer.
- o Reconfiguring the steam turbine to extract steam for the reprocessing plant. This should have no impact on turbine cost.

Table 3-2 summarizes the cost impact of these changes.

TABLE 3-2

ADDITIONAL ETF EQUIPMENT COSTS

Equipment	Additional Cost ($)
Reconfigured Steam Turbine	None
Cooling Tower	100,000
Plant Makeup Water System	20,000
Steam Lines	300,000
Seed Conveyor	100,000

4.0 COMPARATIVE ANALYSIS OF ON-SITE VS OFF-SITE SEED REPROCESSING

4.1 COST OF ELECTRICITY

A comparison was made of the effect of on-site and off-site seed regeneration to the base case i.e. the MHD-ETF CDER which assumes purchasing of seed with no regeneration.

SDD-342 of the MHD-ETF CDER assumes the 16,821 lb/hr of spent seed is recycled, and that 11,068 lb/hr of spent seed will be sold or trucked off-site for reprocessing.

In order to establish a base case for comparison purposes, it will be assumed that the required K_2CO_3 will be purchased on the open market for $525/ton, plus $21/ton delivery based on a 300 mile distance, or a total of 27.3 ¢/lb at the plant. Also, it will be assumed that the spent seed can be sold for 2.5¢/lb.

Although every attempt has been made to make assumptions which are consistent with the information contained in the MHD-ETF CDER, the following cost information is presented for comparison purposes only within the context of this seed reprocessing study:

	Purchase of Seed	On-site Regeneration	Off-site Regeneration
ETF Capital Cost, 1000$	349,500	350,000	349,500
Engel-Precht Capital Cost, 1000$	-	19,600	22,500
ETF O&M Cost, 1000$/yr	17,500	17,500	17,500
Engel-Precht O&M Cost, 1000$/yr	-	2,900	5,400
ETF Fuel Cost, 1000$/yr	4,100	4,100	4,100
ETF Seed Cost, 1000$/yr	12,400	0	0
ETF Seed Credit, 1000$/yr	(1,600)	0	0

	Purchase of Seed	On-site Regeneration	Off-site Regeneration
Plant Rating, KW	202,350	197,636	202,350
Plant Heat Rate, Btu/KWhr	8,972	9,185	8,972
Capacity Factor, hr/yr	5,698	5,698	5,698
Fixed Rate Charge, /yr	0.22	0.22	0.22
Unit Fuel Cost, $\$/10^6$Btu	0.40	0.40	0.40
Use Rate of K_2CO_3, lb/hr	7,992	0	0
Surplus Rate of Spent Seed, lb/hr	16,821	0	0

Table 4-1 compares the effect on cost of electricity of on-site and off-site regeneration on the cost of electricity. On-site regeneration reduces cost of electricty by 0.8 mill/KWhr compared to the purchase of seed. Off-site regeneration of seed reduces the cost of electricity onlv half as much. This is due primarily to not being able to make use of the economics of scale of the integrated plant is providing steam, cooling water and carbon dioxide.

TABLE 4-1

COMPARISON OF THE DIFFERENCE IN THE COST OF ELECTRICITY
FOR ON-SITE AND OFF-SITE SEED REGENERATION
VERSUS THE BASE CASE OF PURCHASING SEED

	On-Site Versus Purchase of Seed (mills/KWhr)	Off-Site Versus Purchase of Seed (mills/KWhr)
ETF Capital Cost	+1.7	0.0
Engel-Precht Capital Cost	+3.8	4.3
ETF O&M Cost	+0.4	0.0
Engel-Precht O&M Cost	+2.6	4.7
ETF Fuel Cost	+0.1	0.0
ETF Net Seed Cost	-9.4	-9.4
TOTAL DIFFERENCE	-0.8	-0.4

4.2 OVERALL IMPACT ANALYSIS

4.2.1 Technical and Economic

Estimates of the impact of added ash flow on combustor performance have indicated that flame temperature and conductivity decrease by 15°F and 4.6 percent respectively. However, a detailed analysis of the chemical and physical changes taking place in the gas stream was not carried out. Unfortunately, without such an analysis, the impact of seed regeneration on the performance of the topping cycle cannot be estimated with a high degree of confidence.

In view of the fact that seed regeneration will have a significantly greater impact on the bottoming cycle, a detailed analysis of the impact of seed regeneration on this cycle was carried out. The net result of integrating the

seed reprocessing plant into the ETF cycle was found to be a 0.88 point drop in efficiency (from 38.03 to 37.15) and a 4.7 MW decrease in net power output.

The total plant investment for the Engel-Precht process in early 1981 dollars is $19,594,000, and an additional $520,000 is required because of necessary changes to the ETF system.

The net effect for the on-site plant of the increase in cost and reduction in efficiency versus the savings on purchased seed is a small decrease in the cost of electricity of less than one percent (0.8 mills/Kwhr). For the off-site non-integrated plant, the decrease in the cost of electricity was smaller, less than one-half percent (0.4 mills/Kwhr). The relatively small difference between cost of electricity probably means that economics along will not decide the seed reprocessing option but other factors will also be important (i.e., technical risk, state of development of the process, complexity of the plant, financial analysis, etc.).

Based on the assumption that spent seed is available at no cost, that only capital costs of process equipment are included, and that steam, electric power flue gas and cooling water are readily available at low cost from the ETF plant, then K_2CO_3 can be produced for as little as 19.1¢/lb. In fact, the cost of production will be higher than this depending upon the accounting procedures employed. The most satisfactory method of evaluating the various seed regeneration options is to make a decision based upon a comparison between the cost of electricity for the integrated plant and the cost of electricity assuming that K_2CO_3 is purchased on the open market. This comparison was made and the cost of electricity was found to be independent of the seed reprocessing method as shown below:

Case	Relative Cost of Electricity	Power Plant Efficiency
No Regeneration (CDER Design)	1,000	38.03
On-site Regeneration	0.992	37.15
Off-site Regeneration	0.996	38.03

4.2.2 Environmental

Taking the environmental impacts of handling spent seed in an on-site seed regeneration plant integrated with a MHD topping plant and a steam bottoming plant as a base line, the environmental effects of handling spent seed off-site can be compared.

The first off-site option to be considered is sale of the spent seed. This will require the mining of potassium sulfate, processing it to potassium carbonate, transportation of make-up seed to the MHD site, and transport of the spent seed to its place of use, all of which have negative environmental impacts. However, as an offset, the spent seed will be a replacement for some

virgin potassium sulfate, so that less virgin material must be mined, no processing will be required, and transportation to the site of sulfate use will be reduced. On balance, a slight increase in environmental impacts will occur if spent seed is sold.

Another off-site option is direct disposal. Environmentally, this is a poor option. Make-up seed will again be needed, no offset will be available, and land will be taken for landfill purposes. The landfill, since it contains soluble potassium sulfate, has a potential for groundwater pollution. Leachate collection and treatment will be required. Transportation associated emissions will increase. Overall, air, land, and water pollutant emissions will increase as compared to on-site spent seed regeneration.

Finally, the case of off-site regeneration is an independent plant remains. Trucking of spent seed from the MHD site to the regeneration site and return of fresh seed will cause an increase in trucking air emissions. Independent plant requirements for a boiler and a cooling tower will result in an increase of emissions as compared to on-site regeneration. Off-site combustion, even though of oil, will release more SO_2 than will MHD coal combustion on-site. Emissions of NO_x may or may not be reduced by off-site combustion as compared to on-site, depending on the control method used at the MHD site and the possible use of low NO_x oil burners off-site. Particulate emissions may be reduced by off-site regeneration. The preparation of boiler feed water and cooling tower water off-site will result in the emission of more water and land pollutants than will preparation on-site due to the inverse economics of scale. Off-site regeneration wastes will be identical to those from on-site regeneration but transportation to final disposal may or may not result in additional air emissions, depending on the relative location of the MHD, regeneration, and waste desposal sites. Utility requirements of an off-site plant will roughly balance those required from the MHD plant by an on--site plant, but since the off-site plants may get them from sources of lower efficiency than an MHD plant, the emissions from their sources can be expected to increase. Considered together, the above analyses indicates that off-site regeneration will result in increased environmental impacts as compared to on-site regeneration. Off-site regeneration, however, is preferable to sale or disposal of spent seed from an environmental standpoint.

4.2.3 Recommendations

A detailed analysis of the chemical and physical changes taking place in the gas stream should be carried out in order to assess the impact of seed regeneration on the performance of the topping cycle.

Various possibilities for extracting low grade heat from the ETF power plant were considered, but in all cases, the impact on net plant efficiency or on equipment cost (due to inadequate temperature differences) could not be justified in terms of reduced cost of electricity. Due to the limited scope of this study, these analyses were based on heat and material balance calculations, engineering judgement, and current commercial practice. The interface between the power generation cycle and the Engel-Precht Process should be examined in greater depth in order to make sure that all low grade heat is being used in the best possible way.

The difference in the total costs for the integrated and off-site cases was estimated by taking major impacts into consideration. The result, based on first year costs, was a small difference in cost of electricity. In view of this small difference, a first year financial analysis study should be carried out in greater detail and a levelized costing analysis should be included. However, prior to initiating such a study it would be advisable to carry out an on-site integration study for the Formate Process in order that the Formate and Engel-Precht Processes can be compared using the same financial analysis parameters.

Both the RCC study and this study were based on an approximate spent seed composition. A spent seed composition based on the impurity rejection capabilities of the selected Engel-Precht or other process should be established before carrying out a detailed engineering evaluation of that process. Detailed energy and mass balances for the integrated plant should then be developed.

The heat and material balance for the Engel-Precht Process which was generated by RCC and scaled in this study employed an overall approach. A heat and material balance over each item of equipment should be carried out during any future process design study.

5.0 ASSESSMENT OF PROCESS CHANGES

5.1 DISCUSSION OF PROCESS CHANGES

Gilbert Associates has considered several changes in the Resource Conservation Company's seed regeneration process. They are as follows:

Sodium Rejection

If sodium is not separately rejected, Module II can be removed from the RCC process flow diagram. In this case, the overflow from the Module I settling tank will pass directly to the KCl makeup tank in Module III. The settling tank temperature should be raised from the 72°F indicated by RCC to 110°F to prevent KCl precipitation. The filtrate will now carry an increased amount of NaCl along with the other dissolved solids, since Module I will become saturated with NaCl. An approximate calculation indicates that it will require 27 to 30 hours of operation to saturate the system. This calculation assumed that NaCl and KCl solubilities are as given in Figure 6 of Reference 1.

Once saturation is obtained, NaCl will precipitate in Module I, being less soluble than the chlorides of potassium and calcium, and will exit the process in the filter cake.

Subsequent modules will run unsaturated because addtional process water is added. Sodium chloride will be carried out of the system via water in the centrifuge cake in Module III. According to Gilbert's assumptions and scaling, and at steady state, this will increase the amount of Na_2CO_3 recycled to the MHD plant from 2,435 lb/hr to 3,336 lb/hr, as shown in Figure 5-1.

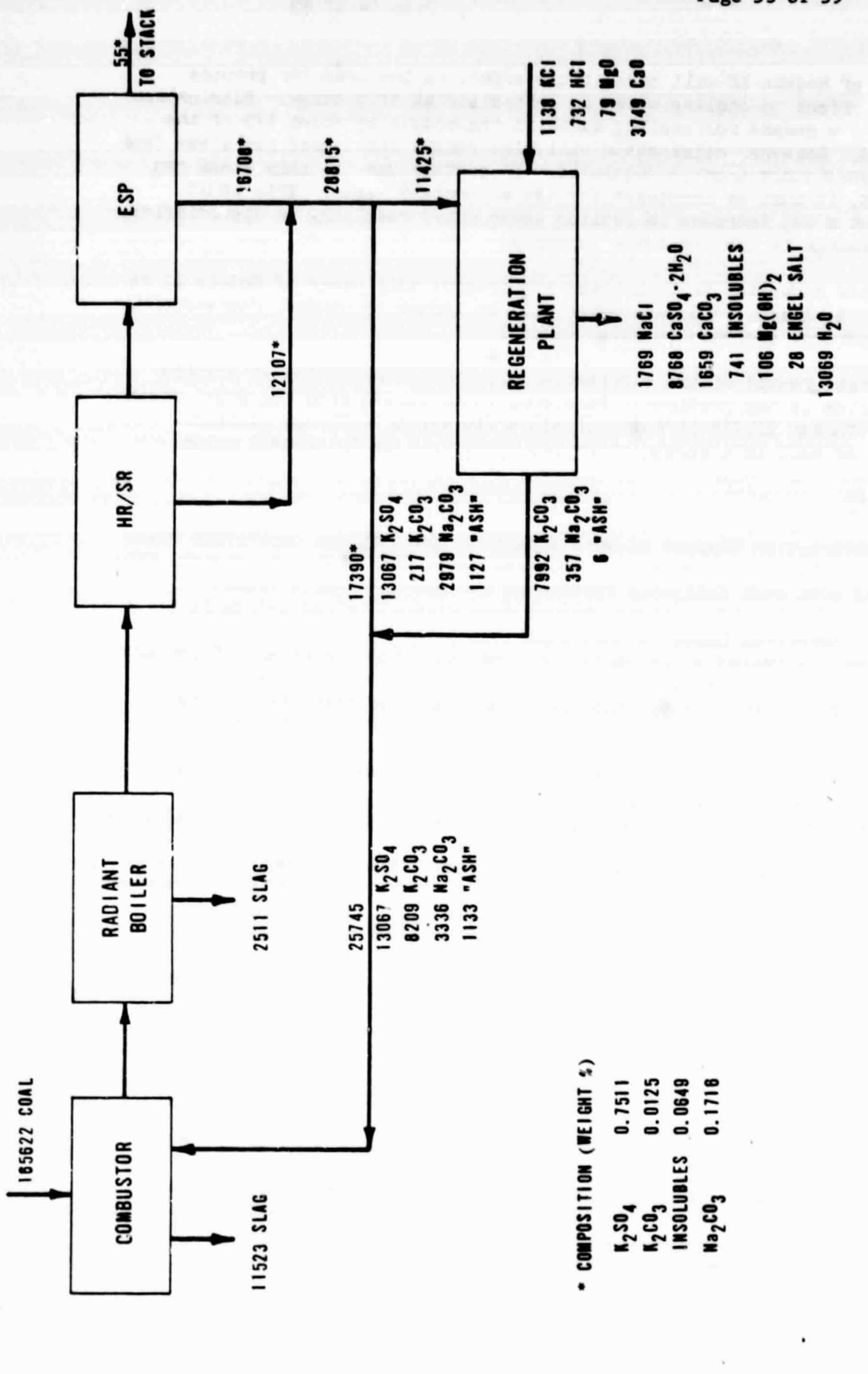


FIGURE 5-1
DOMINANT FLOWS (IN LB/HR) IN ETF SEED
REGENERATION CASE WITHOUT SEPARATE SODIUM REJECTION

Elimination of Module II will have little effect on the need for process water. The effect on cooling water is less clear at this stage. Elimination will reduce the demand for cooling water in the module by about 1/3 of the total demand. However, elimination will also remove the demand for steam from Module VII previously used in Module II. If another use for this steam can not be found, it must be condensed for use as process water. This would require about a 1/3 increase in cooling tower duty, resulting in approximately no overall change in cooling tower capacity.

A considerable reduction in horsepower requirement will occur if Module II is eliminated. At least 1,100 horsepower will no longer be needed, representing about a 42 percent decrease in power demand.

One unfortunate result of the elimination will be the rejection of soluble sodium chloride in the previously insoluble waste stream from the Engel-Precht plant. The former 22,180 lb/hr insoluble waste stream will now contain 1,769 lb/hr of NaCl in a stream of 26,140 lb/hr that is 50 percent water.

Process Water

Resource Conservation Company assumed 3 percent water in the centrifuge cakes and 20 percent in the filter cake. GAI experience with coal ash, flyash, FGD sludges, and even such nonaqeous systems as SRC solids/organic liquid separation, indicates that liquid removal from finely divided solids is difficult. Therefore, based on this experience, the water content of the cakes has been estimated at 25 percent in the centrifuge cakes and 50 percent in the filter cake. This will result in a net increase in process water requirement of 11,000 lb/hr for the GAI assumption over that obtained by directly scaling the Resource Conservation Company's material balance.

The condensate obtained from the steam provided from the MHD topping plant will become contaminated with process salts in the vapor compression evaporators, and will require some cleanup before it can be used for boiler feed water again. However, it is eminently suitable for use as process water. Accordingly, GAI has proposed that it be so used. This will require the MHD plant to slightly increase its output of boiler feed water. This also removes the necessity for a small process water treatment unit in the regeneration plant or the use of potable municipal water as process water.

If regeneration occurs off-site, a regeneration plant boiler and cooling tower will be needed, which will require a water treatment unit. Use of condensate as process water is still recommended with an accompanying increase in the size of the water treatment unit.

Seed Drying

Anhydrous potassium carbonate is a hygroscopic solid that must be protected from atmospheric moisture in order to prevent difficulties in handling. The sesquihydrate does not suffer from this drawback. It is assumed that the regeneration process will produce the hydrate rather than the anhydride as shown in the RCC report. Consequently, the dryer should be located as near the MHD combustor as possible. This will take advantage of ease of

transportation of the hydride, ready availability of MHD flue gas for drying, and minimum handling of hygroscopic anhydride.

In the case of off-site regeneration, dryer location at the MHD topping plant so as to use the MHD flue gas is even more essential. Otherwise, the heat needed for drying will have to be obtained from expensive fuel oil instead of inexpensive coal. Additionaly, the regeneration plant boiler would have to be approximately doubled in size to supply the heat required.

Evaporators

An approximate calculation of the amount of steam made in the two vapor compression evaporators was compared to the steam consumption needed for multiple effect evaporators, assuming that one pound of input steam to the latter will evaporate three pounds of water. This latter energy input was, in turn, compared to the energy needed to run the vapor compressor motors. The steam energy requirement was about 1.5 times the electric energy requirement, leading to the conclusion that the selection by RCC of vapor compression evaporators over multiple effect evaporators is correct.

5.2 COST AND EFFICIENCY IMPACTS OF PROCESS IMPROVEMENTS

The use of multiple effect evaporators instead of vapor compression evaporators would result in a decrease in the electric plant efficiency of 0.15 points, which causes a reduction in net power output and an increase in the cost of electricity of 0.42 percent. Therefore, this change should not be made.

The location of the seed dryer at the ETF instead of at the Engel-Precht plant will result in a shorter flue gas duct run, thus its impact will be beneficial from the standpoint of capital costs in all cases. This is reflected in the costs in Table 5-3.

The impact of increasing the process water content of the cakes will be reflected in the operating and maintenance costs of the regeneration plant, due to an increased demand for process water. This water is obtained from process steam. This could increase the cost of electricity by not more than 0.53 percent which is not significant, being much less than the uncertainty in the assumptions and data used in the calculations.

The removal of Module II results in a 33 percent decrease in the capital cost of the regeneration plant, as shown on Table 5-1. Operation and maintenance cost are decreased by only 3.5 percent, as shown on Table 5-2. These two tables allow the costs of K_2CO_3 regenerated and of electricity to be calculated, using the methods of Sections 2.5.1 and 4.1.1.

Table 5-3 shows the results of these calculations. The reduced capital cost of a regeneration plant without Module II reduces the cost of K_2CO_3 enough to overcome the smaller reduction in electric plant efficiency, so that the cost of electricity is reduced by 2.6 mill/kWh or 2.7 percent. This reduction is within the uncertainty ban but does indicate that if technically feasible this could be a more cost effective seed regeneration option.

5.3 RECOMMENDATIONS

The effects of a number of process changes on the RCC design were evaluated, but the only change that had more than a minor effect on cost and performance was the removal of the module to separate sodium from the spent seed. Sodium is an impurity in the coal in the sense that it has a higher ionization potential than potassium. Potassium is preferred in order to achieve the necessary plasma conductivity in the MHD channel. However, in the final analysis, the extent to which sodium must be removed will depend on a trade-off between the impact of sodium concentration on the cost (due to lower efficiency) of the ETF plant and the cost of sodium rejection equipment.

A detailed analysis of the effect of seed composition on the MHD topping cycle should be carried out. At the same time, the Engel-Precht Process should be redesigned assuming the removal of the sodium rejection module. These analyses should be iterative in the sense that the spent seed composition assumed as a starting point for the process analysis study should be consistent with the composition of the recycle stream calculated on the basis of the changes in chemical composition which take place in the MHD channel.

TABLE 5-1

CAPITAL COSTS OF THE ENGEL-PRECHT PROCESS
WITH AND WITHOUT SODIUM CHLORIDE REJECTION

	NaCl Rejection	Yes*	No
Materials			
Major Components		$ 5,346,000	$ 3,578,000
BOA		1,550,000	1,038,000
	Subtotal	6,896,000	4,616,000
Erection			
Labor Installation		4,620,000	3,093,000
	Total Direct Cost	11,516,000	7,709,000
Indirects		3,234,000	2,165,000
	Subtotal	14,750,000	9,874,000
Engineering		1,180,000	790,000
Other Costs		398,000	247,000
	Total Plant Costs	16,328,000	10,911,000
Contingency		3,226,000	2,182,000
	Total Plant Investment (1/81)	19,594,000	13,093,000

* From Table 2-2

TABLE 5-2

ANNUAL OPERATING AND MAINTENANCE COSTS FOR SEED REPROCESSING WITH AND WITHOUT SODIUM CHLORIDE REJECTIONS (MM$)

Plant Capacity: 11,000 lb/hr Spent Seed
Annual Availability: 5,698 hrs/hr

NaCl Rejection	Yes*	No
Raw Materials		
Lime, ST	0.481	0.481
Potassium Chloride, ST	0.216	0.216
Magnesia, ST	0.012	0.012
Hydrochloric Acid (36%), ST	0.452	0.452
Freight, ST, ST/mi	0.420	0.420
Utilities		
Power, kWh	0.529	0.328
Cooling Water, gal	0.093	0.093
Steam, lb		
60 psig	0.629	0.629
100 psig	0.239	0.239
O&M		
Operating Personnel, hr	0.596	0.596
Supervision	0.119	0.119
Maintenance	0.461	0.461
Insurance & Taxes Allowance	0.196	0.131
Waste Disposal		
Gypsum and Flyash, ST	0.190	0.205
GROSS OPERATING, MM$/Yr	4.633	4.229
By-Products Credits		
Sodium Chloride, ST	(0.251)	-
NET OPERATING, MM$/Yr	4.382	4.229

* From Table 2-3

TABLE 5-3

COMPARISON OF ECONOMICS OF ON-SITE SEED REGENERATION WITHOUT MODULE II(a)

Case	Relative Cost of Electricity	Electric Plant Efficiency (%)
No Regeneration (CDER Design)	1.000	38.03
On-site Without Module II	0.973	37.33

(a) See Section 4.2.1 for economics with Module II included.

REFERENCES:

1. Resources Conservation Company, "MHD Seed Regeneration, the Modified Engel-Precht Process, Task #2 Report," for U.S. Department of Energy, Argonne, Illinois, May 1981.

2. Gilbert Associates, Inc., "MHD-ETF 200 MWe Power Plant Conceptual Design Engineering Report," four volumes, for NASA Lewis Research Center, Cleveland, Ohio, March 1981.

3. Resources Conservation Company, "MHD Seed Regeneration Formate and Engel-Precht Processes Task #1 Report," for U.S. Department of Energy, Argonne, Illinois, February 18, 1980.

ATTACHMENT A

NEW DATA SUBMITTED BY RCC

ATTACHMENT A
NEW DATA SUBMITTED BY RCC

Engel-Precht - 450 MW_t, Rosebud Coal

Overall Water Balance

IN	lb/hr	OUT	lbs/hr	
24	661	4	3,353	
25	2651	7	49	
28	3500	22	1,101	
31	860	25	2,651	
35	2608	41	50,835	
36	465	42	3,652	
37	9721	43	43,626	
39	30998	44	8,165	
40	19083	Flash from 37	202	See Below
54	49807	Cond. into 38	5,102	Condensed into
		Cond. into 53	1,756	Cooling Water
Total	120,354		102,492	in Barometric Condensers

Δ = 138 lb/hr (Within rounding error)

Water flashed from 37

IN	9721 (1)(80-32)	=	466,608 Btu/hr
OUT	(9721 - m)(1)(58-32)	=	252,746 - 26m
	+ (m) (1086.9)	=	1,086.9 m
			1060.9 m + 252,746

m = 202 lbs/hr

Water condensed into 38

IN	212,181 (1)(80-32)	=	10,184,688
	+ m (1112.7)	=	1,112.7m
			1112.7m + 10,184,688
OUT	(212, 181 + m)(1) (105-32)	=	73m + 15,489,213

m = 5102 lb/hr

ATTACHMENT A (Cont'd)

Water condensed from 33

IN	40 = 19083 (1)(9432)	= 1,183,146 Btu/hr
	33 = 3681 (1154.2) + 2086 (.21)(222-32)	= 4,331,842
		5,514,988
OUT	Bottoms to Decomp. = (19083 + m)(1)(180-32)	= 148m + 2,824,284
	Overhead to Cond. = (3681 - m)(1138.2) + 2086 (.21)(180-32)	=-1138.2m + 4,254,547
		7,078,831 - 990.2m

m = 1579 lb/hr

Water condensed into 53

IN

Overhead from D.C. Heater 2102 (1138.2) + 2086 (.21)(180-32)	= 2,457,329
53 = 77040 (1)(80-32)	= 3,697,920
	6,155,249

OUT

Overhead to compressor (pre-34) 2086 (.20)(85-32) + (2102 - m)(1096.8)	= 2,331,871 - 1098.6m
Bottom (C.W. Return) (77040 + m) (1) (105-32)	= 73m + 5,623,920
	7,955,791 - 1025.6m

m = 1756 lb/hr

ATTACHMENT A (Cont'd)

Engel-Precht - 450 MW_t, Rosebud Coal
- NaCl/KCl Fractional Crystallizers
- Overall System Heat Balance

+ 6	= 22924(1)+(34957-22924)(.25)(224-32)	= +4,978,992
- Condensate	= 14957(1)(170-32)	= -2,064,100
- 7	= 49(1)+(1599-49)(.25)(190-32)	= - 68,967
- 8	= 259(1)+(8901-259)(.25)(130-32)	= - 237,111
+ 25-Return = $m\lambda$	= 2651 (957.4)	= +2,538,067
+ 36	= 465(1) (190-32)	= + 73,470
- 38 ΔH	= 212,181(1)(80-32)-(212,181+5102) (1)(105-32)	= -5,676,971
- 48	= 2673(1)+(4514-2673)(.25)(163-32) = -	410,456
+ Heat of crystallation (see next page)		= + 899,673
	NET SURPLUS HEAT	+ 32,597

This would be within rounding error -- i.e. this is 0.38% of the total heat involved ($\pm 8.5 \times 10^6$ Btu/hr).

Heat of Crystallization

Heats of Formation	NaCl(c)	=	-98.23 kcal/gmole	
	NaCl(aq)	=	-97.30	
Heat of Crystallization		=	- 0.93	(exothermic)
Heats of Formation	KCl(c)	=	-104.18 kcal/gmole	
	KCl(aq)	=	-100.06	
Heat of Crystallization		=	- 4.12	(exothermic)

$$\Delta Hx\ (NaCl) = (0.93\ \frac{kcal}{gmole})\ (3.97\ Btu/Kcal)\ (\frac{1}{58.5}\ \frac{gmole}{g})\ (454\ g/lb) = 28.7\ Btu/lb$$

$$\Delta Hx\ (KCl) = (4.12\ \quad)\ (3.97\ \quad)\ (\frac{1}{74.6}\ \quad)\ (454\ \quad) = 99.5$$

To heat given off to surroundings

(28.7 Btu/lb) (1374 lb/hr) + (99.5 Btu/lb) (8642 lb/hr) = 899,673 Btu/hr

GAI Ref. No. 071-368-305
Engineering Study 305

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 305

IMPACT OF NEW MAGNETIC FIELD EXCLUSION FOR PERSONNEL ACCESS

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

GILBERT ASSOCIATES, INC.
P.O. BOX 1498
READING, PA. 19603

AUGUST 1981

TITLE: Impact of New Magnetic Field Exclusion for Personnel Access

SCOPE:

An evaluation was made of the technical and economic impact of the new magnetic field exclusion guidelines, as specified in Specification A4442, Rev. D, of SDD-503, on the ETF conceptual design (Reference 1).

FINDINGS:

Plant layout changes can be made to satisfy the requirements of the aforementioned magnetic field exclusion guidelines.

1) The cryogenic and vacuum support equipment for the magnet can be relocated to meet the DOE Guidelines (Reference 2) with only minor changes to the plant layout.

2) High maintenance components are not located within the 0.01 tesla magnetic fringe boundary which require periodic maintenance during power operation of the MHD generator. Consolidation equipment is suitable for operation in the 0.25 tesla fixed magnetic field.

3) System components, piping, and ductwork located within the high magnetic fields of the magnet are fabricated of stainless steel or other non-magnetic materials.

4) The MHD Building crane can be repositioned to a new storage location which is outside the 0.01 tesla boundary. In this new location, there are no significant magnetic forces on the ferro-magnetic crane components.

5) The increase in overall plant cost for the proposed plant layout changes for this study is $845,000 or approximately 2.5 percent of the estimated total ETF plant cost listed in the CDER.

RECOMMENDATIONS:

It is recommended that this study's alternative plant layout and equipment arrangement be incorporated into the ETF plant design. The features of this alternative layout arrangement are outlined on:

GAI Sketch No. 08-8270-C-671-025 (Proposed Plot Plan)
GAI Sketch No. 08-8270-C-671-026 (Proposed MHD Building Layout)
GAI Sketch No. 08-8270-C-671-027 (Proposed Storage Location of MHD Building Crane)

PROCEDURE:

The MHD-ETF plant layout drawings and the ETF topping side SDD's were reviewed to determine the extent of the following potential problem areas:

1) The location of high maintenance items, such as pumps and compressors, in high magnetic fringe fields (> 0.01 tesla) where personnel access would be limited to less than 1 hour per work day during plant operation.

2) The location of electrical components and instruments in high magnetic fringe fields where the operation of this equipment could be adversely affected and where personnel access would not be possible for periodic checkout or maintenance during plant operation.

3) Large components fabricated from magnetic materials and located close to the magnet (< 70 feet) would be subjected to large magnetic force loadings which would require special consideration in the design of the supporting structures.

4) The stored location of the MHD Building crane as shown on GAI Layout Drawing No. 8270-1-310-010-002, Rev. 1, is within a high magnetic field zone which results in large magnetic forces on the crane components and the supporting crane rails and columns. Repositioning of the crane will be considered so that its stored location during plant operation is outside the high magnetic field areas (< 0.01 tesla).

The plant layout was also reviewed to determine the impact of the new magnetic field boundaries (shown on NML Drawing No. D4444, Rev. B) on all equipment located in the MHD Building and on components in adjacent buildings that are close to the MHD Building walls.

The equipment and plant layout changes generated by the magnetic field exclusion study were evaluated to determine the total increase in ETF plant cost.

DISCUSSION:

The superconducting magnet in the ETF plant design will, when charged, produce relatively high DC magnetic fringe fields in the region around it. This requires special consideration with respect to the layout of high maintenance items. These items are in supporting systems interfacing with the topping side components. A major aspect of this study is the proposed relocation of the cryogenic and vacuum support equipment for the magnet in order to meet the new magnetic field exclusion guidelines as outlined in Reference 2.

The system design description for the Magnet System (SDD-503 of the CDER) contains the data and drawings that specify the required layout scheme for the magnet cryogenic and vacuum support equipment. Included in the attachments to SDD-503 are (1) Specification A-4442, Rev. D, (Reference 2), and (2) NML Drawing No. D-4445, Rev. A, which shows the recommended layout configuration for the magnet support equipment. It is noted that this NML layout includes the addition of several components which were received after the CDER drawings

were prepared. These items are not shown on the CDER layout for these magnet supporting systems (see GAI layout Drawing 8270-1-310-010-001, Rev. 1). These components include a second gaseous helium storage tank, vacuum pump package, utility vacuum pump package, and a hydraulic pump package. For the "roll-aside" magnet scheme (for channel replacement), the NML layout shows the addition of a utility boom and pedestal, and two hydraulic actuators at the magnet. In addition to the above described equipment changes, electrical support components for the magnet have been arranged so that three electrical panels (Dump Resistor & Circuit Breakers, Rectifier & Diodes, and Transformer & Controls) are replaced by two electrical parels (Power Supply Package and Dump Resistors).

The investigation results accommodated the aforementioned NML layout configuration as shown on GAI Sketch No. 08-8270-C-671-026, Rev. 0. This new layout can be accommodated by incorporating the following minor layout changes (see GAI Sketches Nos. 08-8270-C-671-025, Rev. 0, and 08-8270-C-671-026, Rev. 0):

1) Relocation of the Coal Preparation Building from column lines 1e-2 to 1-1e (28 feet to the west).

2) Relocation of the Yard Coal Crusher House a distance of 28 feet to the west. This change is required to maintain the same inclination of the coal belt conveyor between this building and the Coal Preparation Building.

3) Slight rotation and change in total lengths of the coal belt conveyors between the 30-day coal piles and the Yard Coal Crusher House.

4) Providing an outdoor location for the gaseous helium storage tanks (Item 50 on GAI Sketch No. 08-8270-C-671-025, Rev. 0).

This new layout configuration for the magnet support equipment meets the requirements specified on NML Drawing D4445, Rev. A, and outlined in the NML Specification A4442, Rev. D. The powered components, such as the pump packages and liquifier/refrigerator, are relatively high maintenance items and are, therefore, located outside the 0.01 tesla boundary where approved personnel access is allowed for 8-hour workdays, 5 days per week. This exclusion guideline also applies to electrical and instrumentation components that require frequent inspection and/or maintenance. Some instrumentation may be located within the 0.01 tesla boundary; however, the moving parts of these instruments must be constructed of non-magnetic materials. From an operational standpoint, the length of piping and electrical cables between functionally adjacent components are maintained as short as possible. These lengths are the same or less than the corresponding distances shown on the NML suggested layout configuration. Therefore, it is concluded that the proposed GAI layout for the magnet support equipment (Sketch No. 08-8270-C-671-026, Rev. 0) satisfies the latest operational and magnetic field exclusion requirements for the ETF plant.

Since the 0.01 tesla boundary is within the Coal Feed and Seed Feed Buildings, it is recommended that any active equipment (powered components which have

moving parts or subassemblies for the performance of their intended functions) and other high maintenance items in these buildings be located outside of this magnetic fringe boundary. In addition, it is recommended that security-type barriers with warning signs be placed along the 0.01 tesla boundary line and that "Supervisory Administrative Control" be used to limit approved personnel access into this area (>0.01 tesla) to 1 hour per workday as specified in Reference 2. Access to the MHD Building via the railroad tracks should also be included in "Supervisory Administrative Control." Access should be limited to time periods when the magnet is not operating.

As indicated in Reference 2, access for unapproved personnel shall be limited to areas where the magnetic field is less than 0.0005 tesla (no time limit). Therefore, it is recommended that appropriate caution signs be permanently installed around the entire periphery of the plant island (area enclosed by the security fence) to indicate that access is for approved personnel only. In addition, any access to the plant island should be closely controlled as specified in "Supervisory Administrative Control."

The second phase of this study involved the investigation of the magnetic force interactions between the charged magnet and magnetic materials close to the magnet (< 70 feet). Topping side components in the immediate vicinity of the magnet (< 70 feet) are fabricated from non- magnetic materials. Items that interface with the topping side components and are in the immediate vicinity of the magnet, such as piping, valves and ductwork, shall also be non-magnetic materials. The combustor slag collection tanks and the associated piping and valves are fabricated from stainless steel or other non-magnetic materials.

The CDER layouts for the MHD Building, GAI Drawing Nos. 8270-1-310-010-001, Rev. 1, and 8270-1-310-010-002, Rev. 1, were reviewed by the MHD Magnet Group of the Francis Bitter National Magnet Laboratory to determine the maximum magnetic force loadings on the structural members, crane rails and supporting columns for the 150-ton MHD Building crane. Based on this review, the National Magnet Laboratory reported a maximum magnetic force of 0.75 "g" (0.75 times the force of gravity) applied to a supporting column for the fixed crane rail located east of the magnet. This supporting column is located closest to the magnet centerline (approximately 40 feet), and the magnetic force on the column is applied horizontally at a height equal to the elevation of the magnet horizontal centerline. It was concluded that the relatively low magnetic forces exerted on the crane rail supporting columns can readily be accommodated in the overall design of these structural members.

As shown on GAI Sketch No. 08-8270-C-671-027, Rev. 0, the proposed stored location of the MHD Building crane will prevent the generation of any significant magnetic forces between the crane components and the magnet when the magnet is operational. However, it is recommended that the crane be "locked" in this position during plant operation so that the small magnetic forces exerted on the crane components will not start the crane rolling towards the magnet. This locking feature can be provided by incorporating crane drive electrical interlocks and/or physical stops attached to the crane rails.

The increase in overall plant cost for the proposed plant layout changes for the magnetic field exclusion study is $845,000. Almost 90 percent of the added direct costs are attributed to enlargement of the MHD Building. The changes to the coal handling system and magnet support systems are so small that cost changes are considered to be insignificant.

REFERENCES:

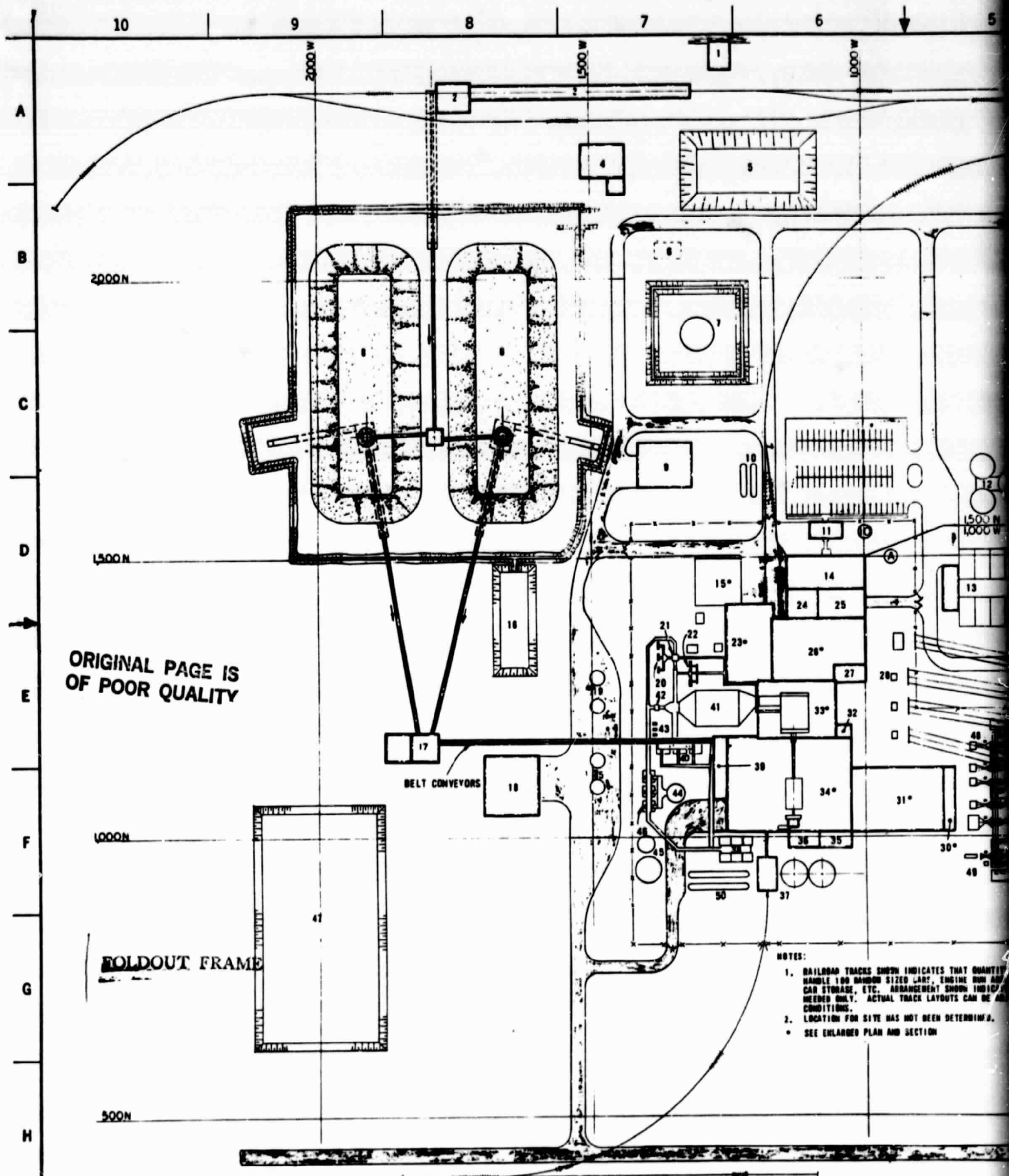
1. Volumes I and II, Magnetohydrodynamics Engineering Test Facility, 200 MWe Power Plant, Conceptual Design Engineering Report (CDER).

2. Specification A4442, Rev. D, (from SDD-503), "MHD-ETF 200 MWe Power Plant Magnet System, Interim Criteria for Personnel and Equipment Exposure to Magnetic Fields", Issued by Francis Bitter National Magnet Laboratory, M.I.T., Cambridge, MA.

ATTACHMENTS:

GAI Sketches:

08-8270-C-671-025, Rev. 0.	Proposed Plot Plan - Magnetic Field Exclusion Study (Task 305)
08-8270-C-671-026, Rev. 0.	Proposed MHD Building Layout - Plan - Magnetic Field Exclusion Study (Task 305)
08-8270-C-671-027, Rev. 0	Proposed MHD Building Layout - Section - Magnetic Field Exclusion Study (Task 305)



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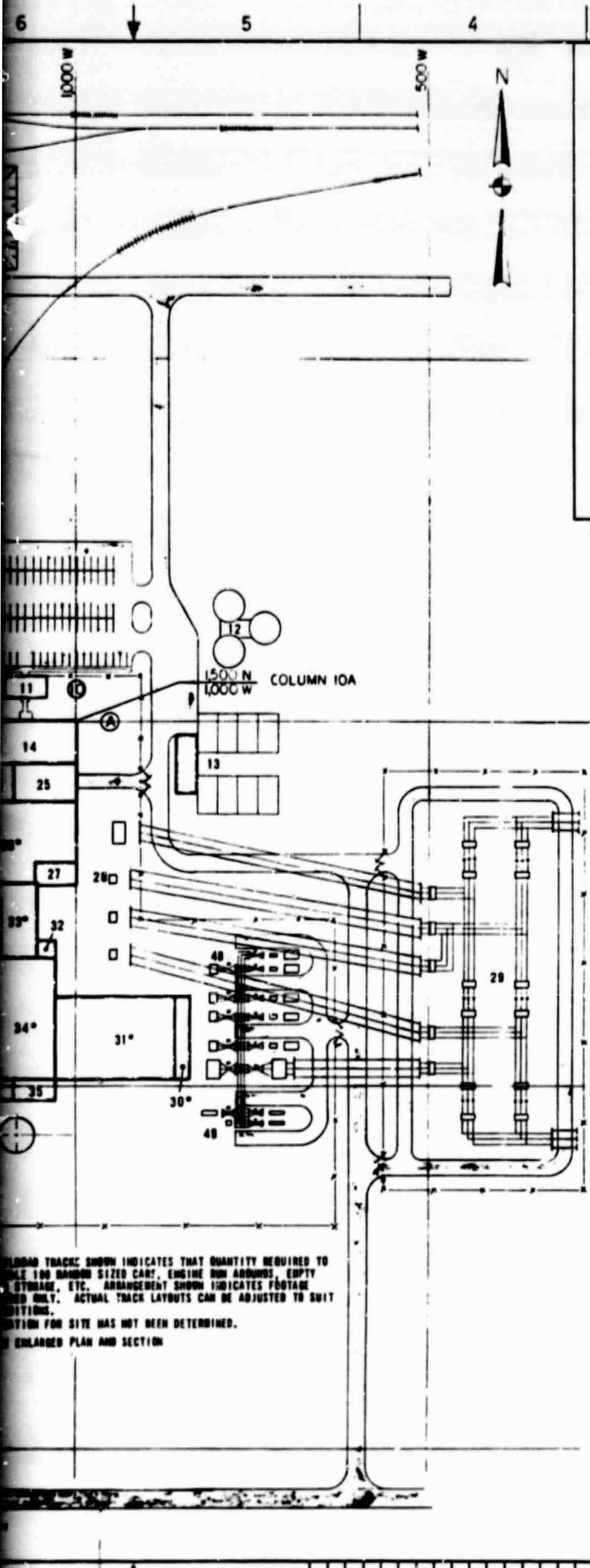
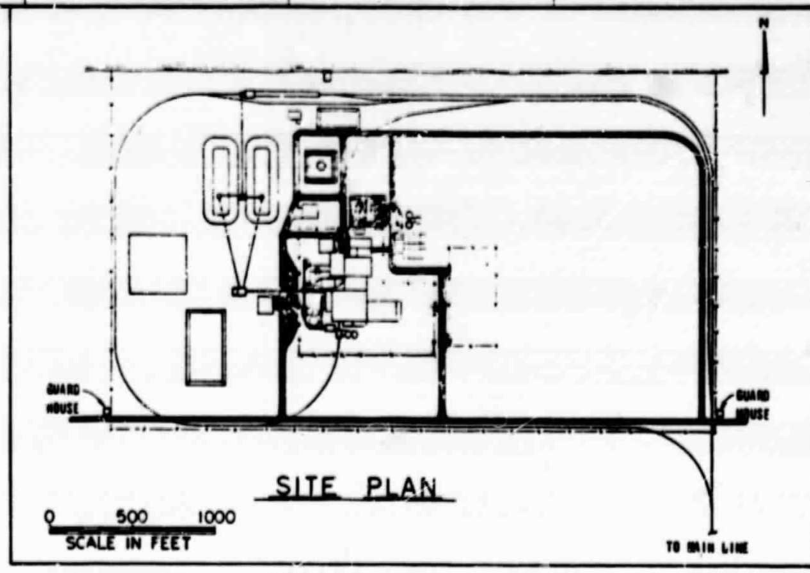
NOTES:
1. RAILROAD TRACKS SHOWN INDICATES THAT QUANTIT
HANDLE 100 RANDOM SIZED CARS, ENGINE RUN A
CAR STORAGE, ETC. ARRANGEMENT SHOWN INDIC
NEEDED ONLY. ACTUAL TRACK LAYOUTS CAN BE A
CONDITIONS.
2. LOCATION FOR SITE HAS NOT BEEN DETERMINED.
* SEE ENLARGED PLAN AND SECTION





SITE PLAN

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SCALE IN FEET

LEGEND

1. INTAKE STRUCTURE
2. ROTARY CAR DUMPER
3. CAR THAWING SHED
4. COAL SYSTEM CONTROL BUILDING
5. STORMWATER RUNOFF BASIN
6. OIL/WATER SEPARATOR
7. FUEL OIL TANK, DIKE AND PUMP HOUSE
8. 30 DAYS COAL PILE STORAGE (EACH)
9. WAREHOUSE
10. LIQUID OXYGEN TANKS
11. MAIN GUARD HOUSE
12. STORAGE TANKS–FILTERED, FIRE SERVICE, RAW WATER AND CONDENSATE
13. COOLING TOWERS
14. ADMINISTRATION, SERVICE AND MACHINE SHOP
15. AIR SEPARATION UNIT
16. COAL PILE RUNOFF BASIN
17. YARD COAL CRUSHER HOUSE
18. SANITARY, INDUSTRIAL WASTE SLUDGE TREATMENT BUILDING
19. SPENT SEED AND FLY ASH SILOS
20. AFTERBURNER GAS FANS
21. AIR HEATER
22. FLUE GAS RECYCLE FANS
23. AIR AND OXIDANT COMPRESSOR BUILDING
24. AUXILIARY BOILER BUILDING
25. WATER TREATMENT AND DEMINERALIZATION BLDG.
26. TURBINE - GENERATOR BUILDING
27. CONTROL COMPLEX
28. TRANSFORMERS
29. SWITCHYARD
30. SWITCHGEAR BUILDING
31. INVERTER BUILDING
32. MISCELLANEOUS GAS STORAGE BUILDING
33. HEAT AND SEED RECOVERY BUILDING
34. MHD BUILDING
35. SEED FEED BUILDING
36. COAL FEED BUILDING
37. SEED UNLOADING FACILITY
38. BAGHOUSE
39. COAL PREPARATION BUILDING
40. COAL DRYING FANS
41. ELECTROSTATIC PRECIPITATOR
42. LOW TEMPERATURE ECONOMIZER
43. TRANSPORT GAS COMPRESSORS
44. CHIMNEY
45. DEWATERING BINS, SETTLING & SURGE TANKS
46. I.D. FANS
47. SLAG DISPOSAL POND
48. HARMONIC FILTERING
49. POWER FACTOR CORRECTION
50. GASEOUS HELIUM STORAGE TANKS

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SCALE IN FEET
REFERENCE DRAWING
PLOT PLAN 8270-1-210-007-001

...LROAD TRACKS SHOWN INDICATES THAT QUANTITY REQUIRED TO ...LE 100 RANDOM SIZED CARS, ENGINE RUN AROUNDS, EMPTY ... STORAGE, ETC. ARRANGEMENT SHOWN INDICATES FOOTAGE ...ED ONLY. ACTUAL TRACK LAYOUTS CAN BE ADJUSTED TO SUIT ...ITIONS.
...TION FOR SITE HAS NOT BEEN DETERMINED.
... ENLARGED PLAN AND SECTION

	CONCEPTUAL DESIGN ISSUE	
8-24-81	PRELIMINARY ISSUE	PLL
9-14-81	FINAL ISSUE	PLL
ISS. DATE	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

PROPOSED PLOT PLAN
MAGNETIC FIELD EXCLUSION STUDY (TASK 305)
200 MWE

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD.
DATE

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ENGINEERS AND CONSULTANTS READING, PA

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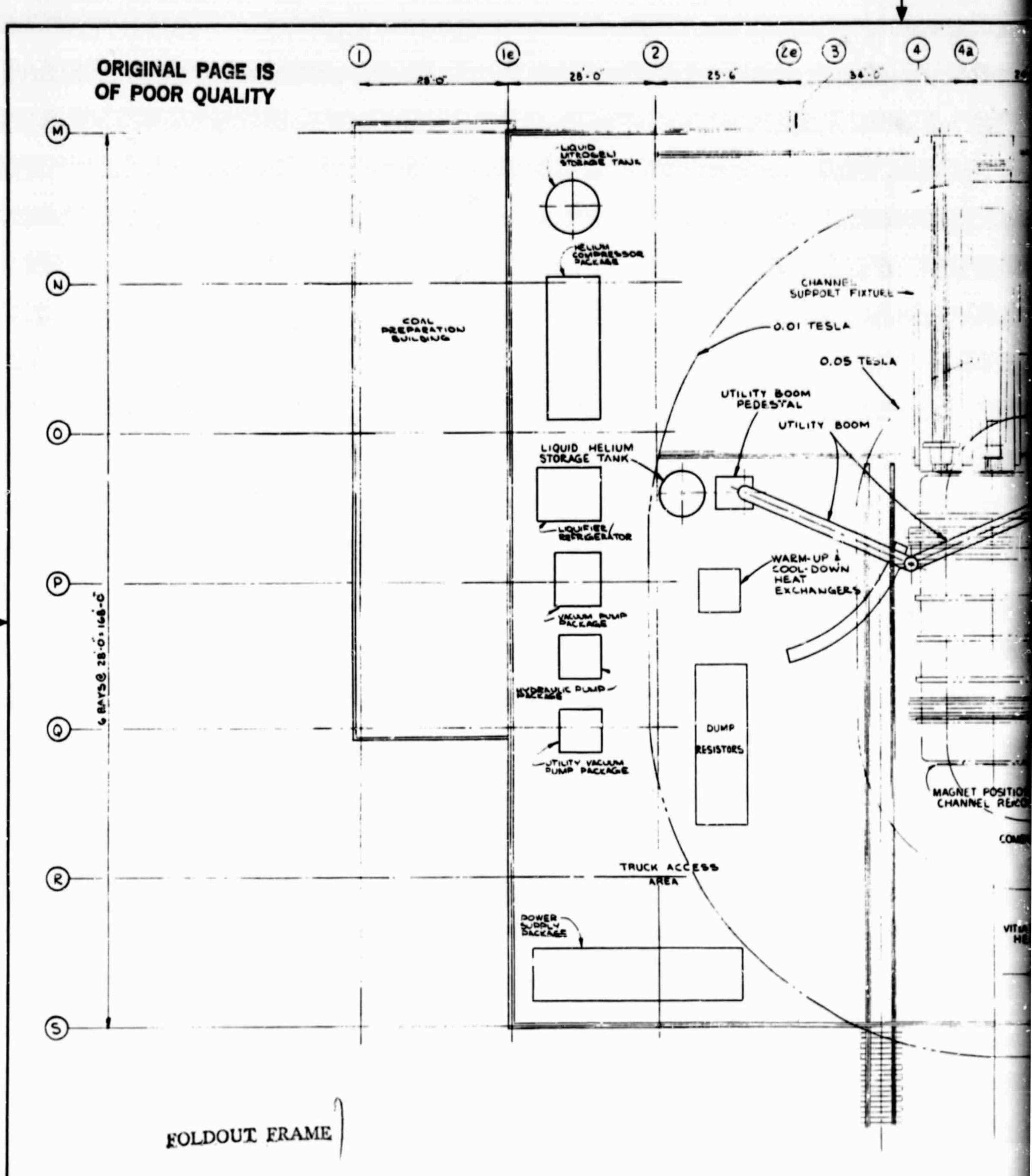

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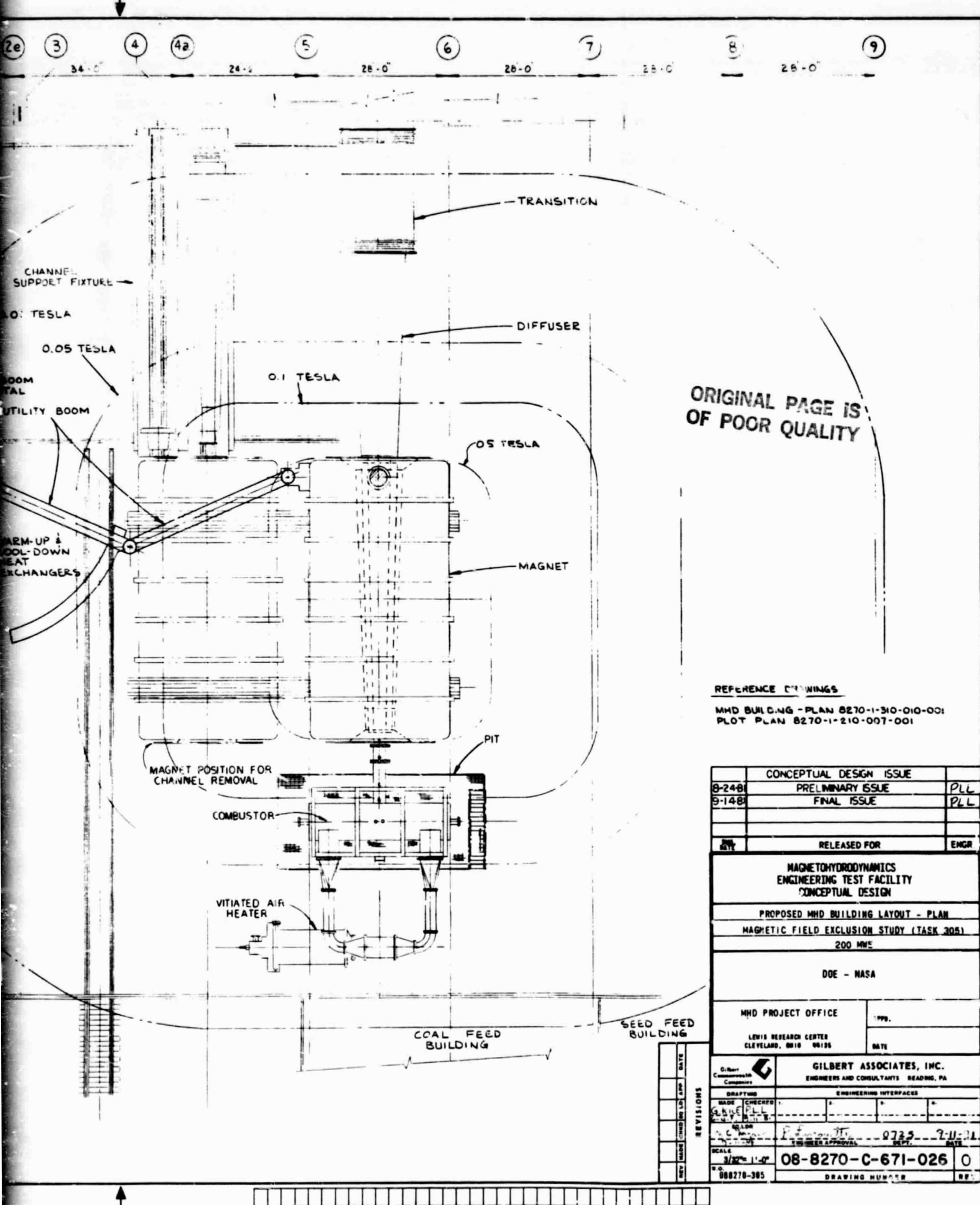

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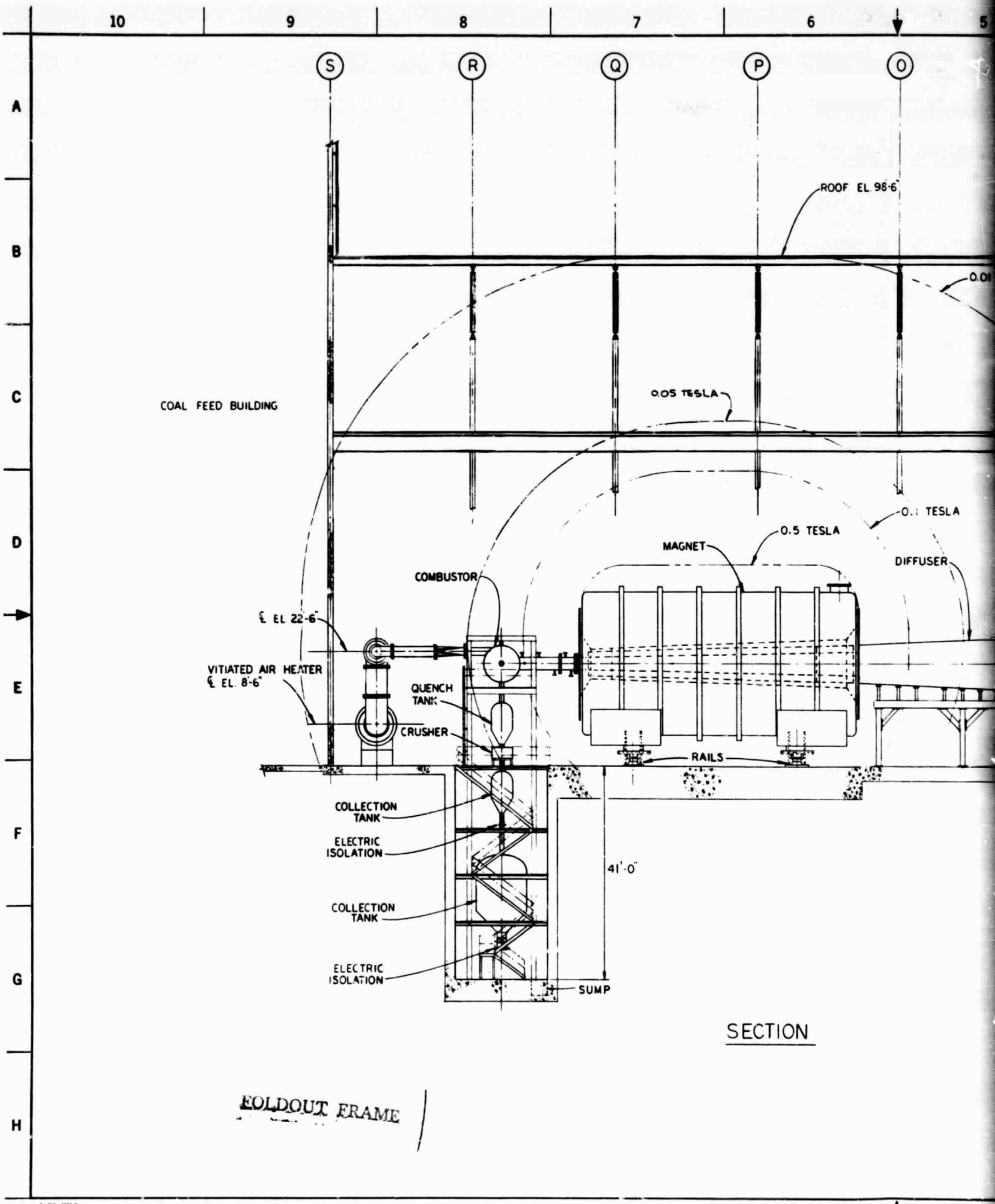

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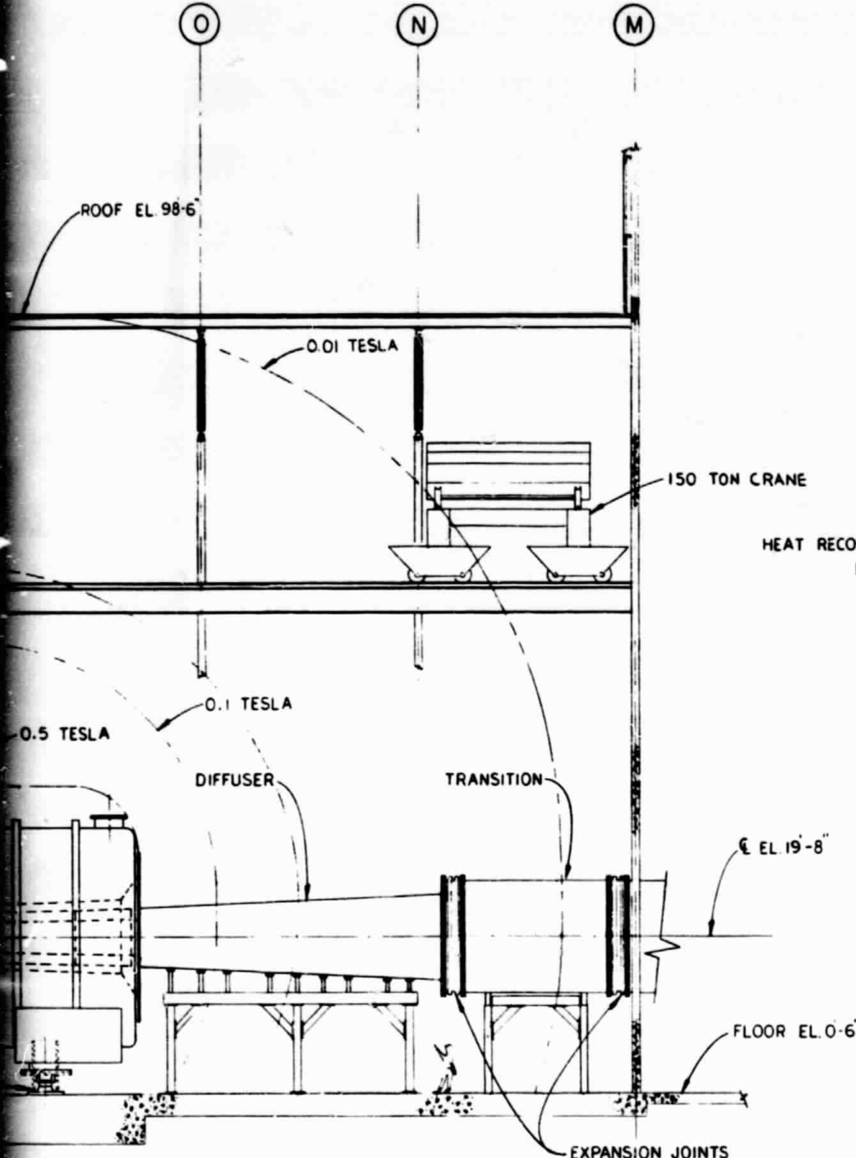

ION

REFERENCE DRAWINGS

MHD BUILDING - SECTION 8270-1-310-010-002
MHD BUILDING - PLAN 8270-1-310-010-001

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	CONCEPTUAL DESIGN ISSUE	
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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

PROPOSED MHD BUILDING LAYOUT - SECTION

MAGNETIC FIELD EXCLUSION STUDY (TASK 305)

200 MWE

DOE - NASA

MHD PROJECT OFFICE APPD.

LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135 DATE

REVISIONS

Gilbert Commonwealth Companies

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING — MADE: G. KILE — CHECKED: PLL

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08-8270-C-671-027 — DRAWING NUMBER — REV 0

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GAI Ref. No. 071-360-306
Engineering Study 306(1)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 306(1)

CHANNEL REPLACEMENT-
CHANNEL DOWNTIME AND ITS EFFECT ON SYSTEM AVAILABILITY

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

GILBERT ASSOCIATES, INC.
P.O. BOX 1498
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SEPTEMBER 1981

TITLE: Channel Replacement--Channel Downtime and Its Effect on System Availability

SCOPE:

The effects of MHD channel reliability indices on system availability were evaluated. Mean time between failures (MTBF) of the channel and the time and techniques to place a new or repaired channel in operation were analyzed. Frequency and duration of failure of the channel were compared with other major subsystems to decide whether special efforts for improvement of system availability were warranted.

FINDINGS:

MTBF of the channel was assessed nominally at 2,000 hours and outage time per failure was estimated at 45 hours. These times are comparable to those of boiler systems in commercial power plants of the same rating. Channel downtime would reduce plant availability by about 2 percentage points. Channel MTBF of 3,000 hours with downtime per failure of 45 hours would result in a 1 point decrease in plant availability.

RECOMMENDATIONS:

- MTBF of 2,000 hours is a necessary component accomplishment to avoid deleterious effect on the power plant performance.

- Since assigned channel MTBF and outage times were comparable to those of other subsystems in commercial power plants, extraordinary efforts to improve MTBF or reduce outage time were considered not warranted. Improvements, once the assigned level (for commercial operations) is reached, can be evolutionary and in line with continuing design and developmental effort applied to the other major power plant subsystems.

- Major factors in the selection of channel replacement techniques should be:

  - Minimal degradation of operating performance.

  - Reliability and simplicity of replacement procedures.

  - Efficient utilization of available space, equipment and manpower.

PROCEDURE:

The objective of the study is to estimate availability of the ETF Power Plant and the effect of channel outages on plant availability. The basic procedure is to categorize the various kinds of outages that can occur and separate them into those due to the channel and the rest of the power plant.

Power Plant Outages are classified as forced, maintenance or planned, according to Edison Electric Institute/National Electric Reliability Council (EEI/NERC) definitions. Maintenance outages are those that cannot be postponed beyond the next weekend and are necessary to prevent more serious consequences, forced outages. Planned outages are scheduled well in advance to coincide with system low load periods. In each category, outages can be full or partial.

Two indices are usually defined for the availability of a power plant. These are: 1) operating availability, which is the proportion of time a power plant was available for operation, without regard to the capacity level at which it could be operated and whether or not it is actually operated and connected to the system, and 2) equivalent availability, which accounts for partial outages or capacity reductions by prorating the time on partial outage to an equivalent full outage of a plant operating at full capacity. For example, a 4-hour reduction to 75 percent capacity is equal to a full 1-hour outage. Equivalent availability is a more realistic index of power plant productivity and will be used in this study.

In a series system, i.e., a system in which each component must be available for the system to be available, such as the ETF, forced outages, which occur randomly, do not overlap. There is some overlap between components in maintenance outages. During a planned outage, each component may be maintained during that time interval so that the sum of component outage hours can be several times the actual period the total power plant is on outage. Because of this difference, it is necessary to consider planned outage hours on a different basis for comparisons than forced or maintenance outage hours. The product method, where component or subsystem availabilities are multiplied to obtain system availability. gives pessimistic and erroneous results due to the overlapping outages and the lack of statistical independence between component outage times.

Planned outage hours are considered separately in this analysis of the availability of the ETF Power Plant and the effect of channel downtime. It is estimated that the entire plant will be out of service for one month in a year for planned maintenance, inspection and overhaul. These planned outage hours should not be allocated among subsystems and components of the plant.

Forced outage and maintenance outage hours, however, were assigned to subsystems of the plant. The data on these outage hours is available from EEI publications on a unit year basis. Since power plant equipment, even in a baseload plant, does not operate continuously throughout the year (8,760 hours), it is not exposed to failure part of the year. The failure rates on unit year basis are adjusted to account for this fact by multiplying

with the plant service factor, typically 0.8 for units of the size of ETF. The plant service factor is the proportion of calendar time the plant operates at some net capacity.

Plant Availability is calculated on the basis of the total outage hours, i.e., planned, full and partial forced and maintenance. The unavailability contribution of the channel is obtained directly as channel outage hours divided by period hours (8,760 per year).

DISCUSSION:

Data on full forced and maintenance outages of bottoming cycle components was obtained from EEI publication 76-85 (Reference 1). Data on partial outages and on applicable components in the boiler subsystem was obtained from a companion publication that lists outage hours on individual components (Reference 2). The outage hours used for the bottoming cycle components are realistic and include full forced, partial forced and maintenance outage hours.

For components in the topping cycle other than the channel, Delphi-type estimates made by project personnel familiar with MHD systems were used. The Delphic method is a technique to solicit, synthesize, and correct or improve individual and group judgement. A group of specialists supply estimates of failure characteristics anonymously and are given an opportunity to revise judgements based upon estimates of the other experts. After a few iterations, the estimates are averaged to obtain the final values for use in the assessments. These Delphi-type estimates reflect best available engineering judgment regarding full and partial forced outages and maintenance requirements. In the absence of any operating data, there is less confidence in the estimates of performance of these novel components than in the bottoming cycle data.

Nominal MTBF assigned to the channel was 2,000 hours. This places it in the category of boiler subsystems for outage incidents per year. Outage time per incident was evaluated at 45 hours. (Channel replacement sequences and times are discussed in Subtask 306-2, Channel Replacement - Arrangement and Evaluation of Alternatives.) This outage time compares favorably with that for boiler tube repair.

Estimated annual channel outage hours = $\frac{8,760}{2,000} \times 45 =$ 197 hours.

Estimated outage time of other topping cycle components	=	539 hours.
Bottoming cycle subsystem outage time (forced and maintenance)	=	425 hours.
Total unplanned outage hours	=	1,161 hours.

Adjusted unplanned outage hours = 1,161 x 0.8 = 929 hours.

Planned outage hours = 730 hours.

Total Power Plant outage hours = 1,659 hours.

Power Plant Availability $= 1 - \frac{1,659}{8,760} = 81\%$

Unavailability due to channel outages $= \frac{197 \times 0.8}{8,760} = 1.8\%$

The power plant equivalent availability of 81 percent is in the same range as that of medium size fossil units. If the estimated parameters of 2,000 hours MTBF and 45 hours replacement time for the channel can be realized, it would appear that the channel will not be a limiting factor in ETF availability. Extraordinary effort to improve channel MTBF or reduce channel replacement time is not warranted since plant availability with a perfect channel will be only 1.8 percent higher. An improvement of channel MTBF to 3,000 hours will improve availability by 0.75 percent or reduce outage time by 66 hours per year. Reduction of channel MTBF to 1,000 hours instead of the nominal 2,000 hours will result in power plant equivalent availability of 79 percent with a corresponding increase in outage hours due to the channel of 197 hours, or 157.6 hours corrected by the plant service factor.

It was assumed in the foregoing analysis that a spare channel will be available to replace a failed channel and that actual repair time for the failed channel will be short enough (about 200 hours) that the spare channel is not likely to fail before repairs of the failed channel can be completed. Calculations indicate that there will be a 2 percent reduction in plant availability if channel repair time is 500 hours and only one spare channel is available.

REFERENCES:

1. EEI Publication 76-85, "Report on Equipment Availability for the Ten-Year Period, 1966-1975", Prime Movers Committee, Edison Electric Institute, 1976.

2. EEI Publication 76-85A, "EEI Equipment Availability Component Cause Code Summary Report 1975", Edison Electric Institute, 1977.

GAI Ref. No. 071-361-306
Engineering Study 306(2)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 306(2)

CHANNEL REPLACEMENT-
ARRANGEMENT AND EVALUATION OF ALTERNATIVES

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

GILBERT ASSOCIATES, INC.
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READING, PA 19603

SEPTEMBER 1981

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TITLE: Channel Replacement - Arrangement and Evaluation of Alternatives

SCOPE:

Plant outage time incurred by replacement of the channel assembly was evaluated for the reference design. Calendar hours and man-hours were calculated for shutdown and cooldown from full load, channel replacement and startup to full load. Three other alternatives were evaluated, two involving movement of the magnet and one with the magnet fixed.

FINDINGS:

Requirements for replacing the channel with the roll aside magnet design (reference design) were 19.5 calendar hours and 191 man-hours. Shutdown, cooldown and subsequent startup back to full load added 25.5 calendar hours for a total of 45. For replacement time, a split magnet was best, needing 16.5 calendar hours and 155 man-hours. The split magnet also allowed in-place inspection and reduced by pass piping and valving requirements. None of the alternatives imposed major penalties for channel replacement.

RECOMMENDATIONS:

Based on channel replacement time and labor required a split channel arrangement is preferred. However, since none of the alternatives imposed major penalties, there should be further study on the design and operational effects on the magnet and interfacing systems.

PROCEDURE:

A channel replacement sequence was established for the reference concept which utilized a roll-aside magnet. During replacement the plant is not generating any power, the magnet field is insignificant, and temperature levels are reduced to permit access by personnel for the tasks to be performed. These initial conditions are defined as part of the shutdown and cooldown analysis which was done independently and then phased in with the channel replacement sequences.

Three main phases of channel replacement were:

1. Disconnect

   - Establish feedwater bypass flow and vent and drain the bypassed loops.
   - Disconnect cooling loop flanges from the sections to be moved or removed.
   - Disconnect gas loop flanges from the sections to be moved or removed. Secure and store the removed section (nozzle).
   - Disconnect channel electrical harnesses.
   - Disengage the magnet fixed supports and jack down magnet until settled on rollers.

2. Magnet Movement and Channel Replacement

   - Roll magnet 34 feet to replacement area.
   - Remove defective channel and insert new channel.
   - Roll magnet with inserted channel back to operational position.

3. Reconnect

   Essentially a reverse of disconnect.

Water side flange disconnect times were established as a function of flange size and pressure rating, based on industry and pipefitter union standards. Ducting flange disconnect times were estimated from the number of bolts and times established per bolt removal.

Channel replacement sequences were reviewed similarly for a rotated magnet arrangement, a split magnet assembly, and a fixed magnet arrangement. For the rotated magnet, the removable section/diffuser and the removable section/nozzle were removed to provide pivot clearance, and the appropriate feedwater bypasses incorporated. With the split magnet only channel feedwater bypass and channel removal were needed, but the channel had to be disengaged from

floor supports. With a fixed magnet arrangement, the entire diffuser assembly, including transition piece, is removed and appropriate bypass and drainage established.

Plant shutdown and cooldown sequences were established independently and then correlated with the disconnect phases of channel replacement. In particular, feedwater drainage and bypass flow had to be coordinated with boiler temperature gradient and steam side cooling requirements. Similarly, the subsequent startup sequences to full load were done independently and then coordinated with the reconnect phase of channel replacement.

Modifications to the reference design, to reduce outage time, were reviewed. These included incorporation of closed loop cooling for the channel and improved space and component arrangements to accommodate channel pull if alternative magnet arrangements were selected in lieu of the present reference case.

Recommendations were made based on the resultant hour, man-hour requirements, complexity of changeout equipment, and techniques and intangibles such as estimated probability of something going wrong.

DISCUSSION:

It is estimated that the MHD channel will have a mean time between failure, (MTBF) when in commercial operation, of, nominally, 2,000 hours. Since the channel operates within the bore of the enveloping magnet, facilitated access for replacement and repair of a malfunctioning channel are essential.

Current procedure for replacement of the channel is:

1. Shutdown plant power system.
2. Cooldown MHD equipment and adjacent area (radiant boiler).
3. Disconnect upstream (nozzle) and downstream (diffuser) channel transition piece flanges, piping and electrical connection.
4. Disconnect magnet tie downs and settle magnet on rails transverse to magnet axis.
5. Move magnet on rails 34 feet to channel removal location.
6. Move cradle with removal fixture and replacement channel into position.
7. Remove faulted channel.
8. Insert replacement channel.
9. Hoist faulted channel over magnet cryogenic piping supply boom to rail car for removal and repair.

10. Reverse steps 5 through 3.

11. Run system checks.

12. Bring power plant back on stream.

Each of the steps delineated above is time-consuming and complex. Shutdown, cooldown and subsequent checkout and startup (steps 1, 2, 11, 12,) will be common to any replacement technique regardless of magnet arrangement. Alternative means of mechanically replacing the channel have been investigated. These include:

- pivoting the magnet
- splitting the magnet
- removing the diffuser assembly to allow the channel to be pulled and replaced without disturbing the magnet

They are described in the following text.

Arrangements and Techniques for Channel Replacement

Present Boundaries and Equipment Configuration

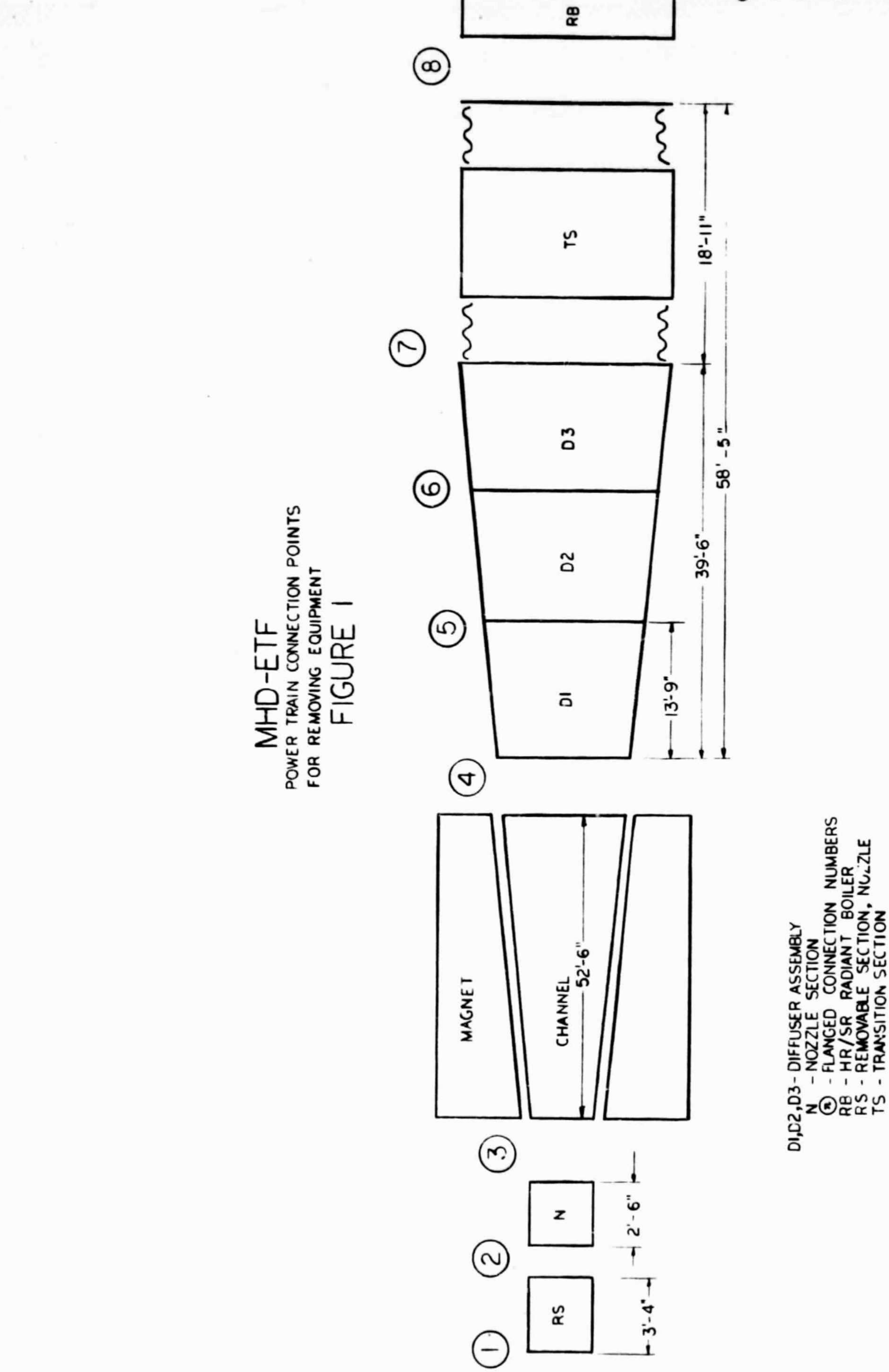
Referring to Figure 1, critical dimensions are:

Channel Length	52' - 6"
Nozzle	2' - 6"
Removable Section (Nozzle-Scaled)	3' - 4"
Diffuser	39' - 6"
Removable Section (Diffuser)	13' - 9"
Transition Section	18' - 11"
Channel/Diffuser Flange to Boiler Wall	58' - 5"

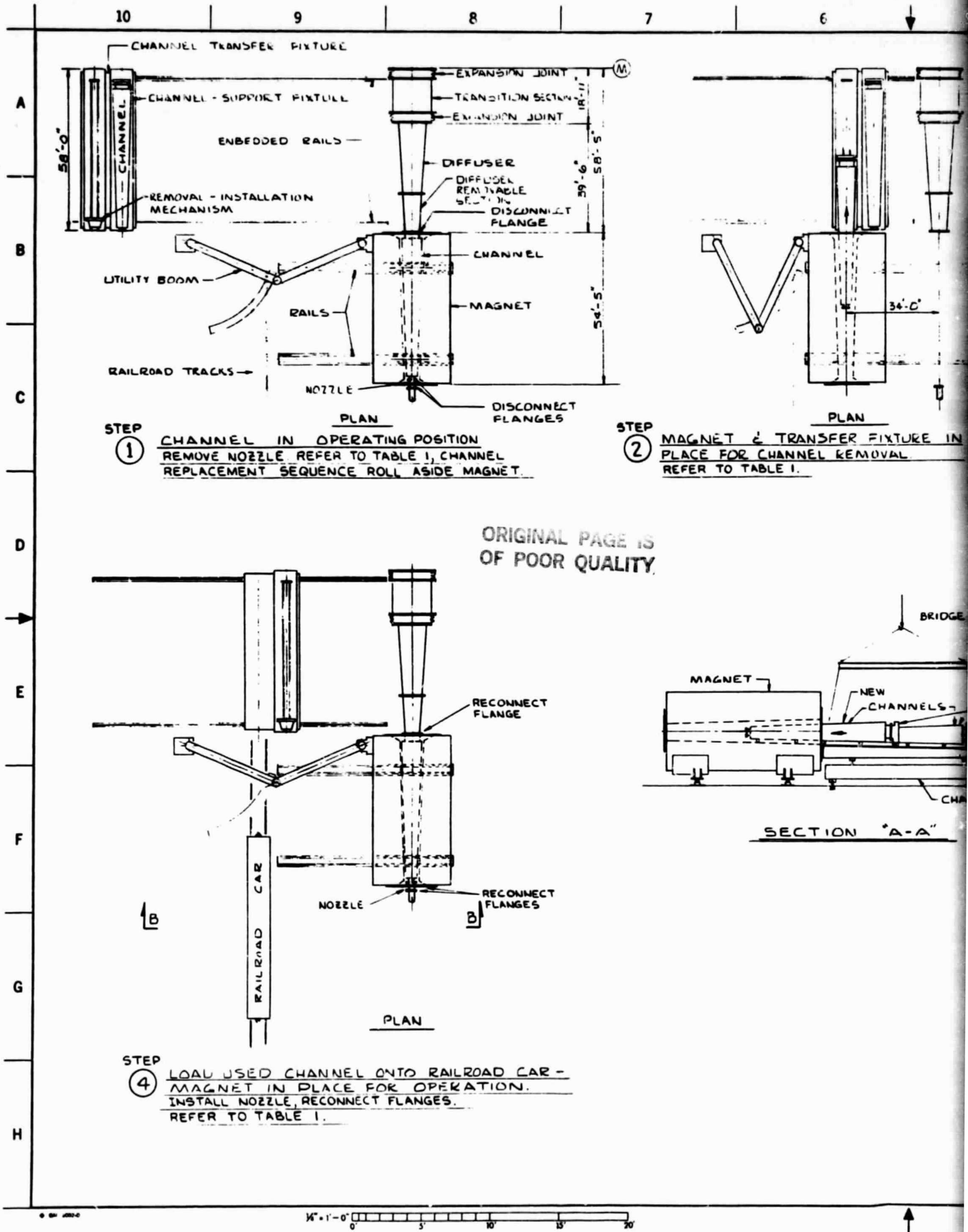
It is not clear from the MHD Power Train System data supplied how the transition section, with expansion joints at upstream and downstream end, is attached or what allowances have been made for flanges and tie rods. However, assuming that end flanges are included in the length of 18' - 11" and since the downstream flange is at the boiler structural wall, pull space for the channel in the axial direction is 58' - 5". For the channel positioned on the cradle, there is only 5' - 11" clearance at the back end of the cradle for winches, pneumatics and access.

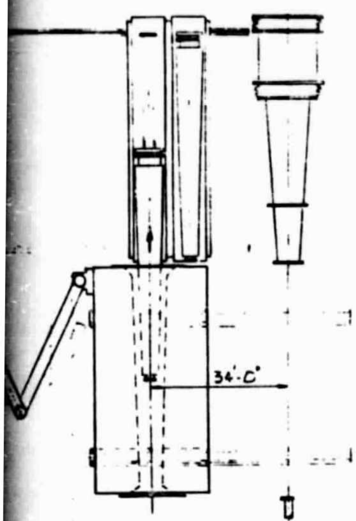
Roll-Aside Magnet

Current concepts for the ETF show a magnet which can be rolled on tracks 34 feet laterally to the channel removal area. This sequence is illustrated in Drawing C-673-030 and Figures 2 and 3 and tabulated in Table 1.



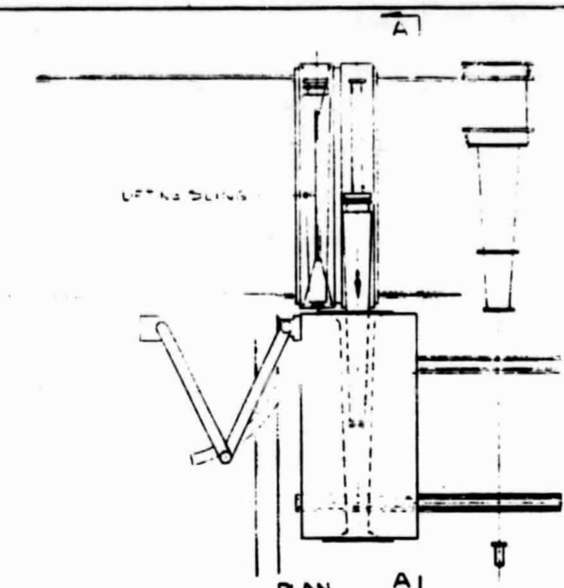
MHD-ETF
POWER TRAIN CONNECTION POINTS
FOR REMOVING EQUIPMENT
FIGURE 1


10
9
8
7
6
A
B
C
D
E
F
G
H
CHANNEL TRANSFER FIXTURE
CHANNEL - SUPPORT FIXTURE
CHANNEL
58'-0"
EMBEDDED RAILS
REMOVAL - INSTALLATION MECHANISM
EXPANSION JOINT
TRANSITION SECTION
EXPANSION JOINT
DIFFUSER
DIFFUSER REMOVABLE SECTION
DISCONNECT FLANGE
18'-11"
39'-6"
58'-5"
54'-5"
CHANNEL
MAGNET
UTILITY BOOM
RAILS
RAILROAD TRACKS
NOZZLE
DISCONNECT FLANGES
PLAN
STEP
1
CHANNEL IN OPERATING POSITION
REMOVE NOZZLE REFER TO TABLE I, CHANNEL
REPLACEMENT SEQUENCE ROLL ASIDE MAGNET.
34'-0"
PLAN
STEP
2
MAGNET & TRANSFER FIXTURE IN
PLACE FOR CHANNEL REMOVAL
REFER TO TABLE I.
RECONNECT FLANGE
RAILROAD CAR
NOZZLE
RECONNECT FLANGES
B
B
PLAN
STEP
4
LOAD USED CHANNEL ONTO RAILROAD CAR -
MAGNET IN PLACE FOR OPERATION.
INSTALL NOZZLE, RECONNECT FLANGES.
REFER TO TABLE I.
BRIDGE
MAGNET
NEW
CHANNELS
SECTION "A-A"
1/4" = 1'-0"
0'
5'
10'
15'
20'



PLAN

... TRANSFER FIXTURE IN
... CHANNEL REMOVAL
... TABLE 1.



PLAN

STEP (3) TRANSFER FIXTURE IN PLACE FOR INSERTION OF NEW CHANNEL — CONNECTION OF CRANE TO USED CHANNEL SUPPORT FIXTURE FOR LIFTING
REFER TO TABLE 1.

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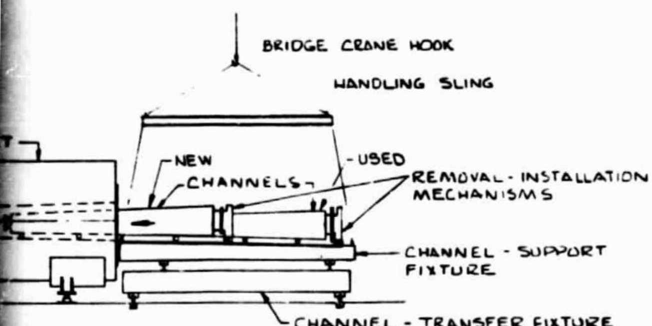
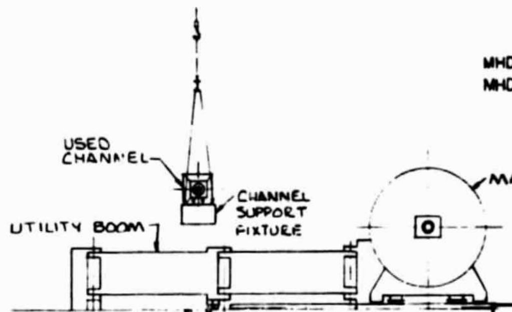


SECTION "A-A"



SECTION "B-B"

REFERENCE DRAWINGS

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MHD BUILDING - 8270 - 1 - 310 - 010 - 002

	CONCEPTUAL DESIGN ISSUE	
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9-14-81	FINAL ISSUE	
	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

LAYOUT SEQUENCES-PLANS & SECTIONS
CHANNEL REPLACEMENT, ROLL-ASIDE MAGNET (TASK 305)
200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPR.
DATE

REVISIONS

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

SCALE 1" = 20'-0"
08-8270-C-673-030
REV 0
DRAWING NUMBER

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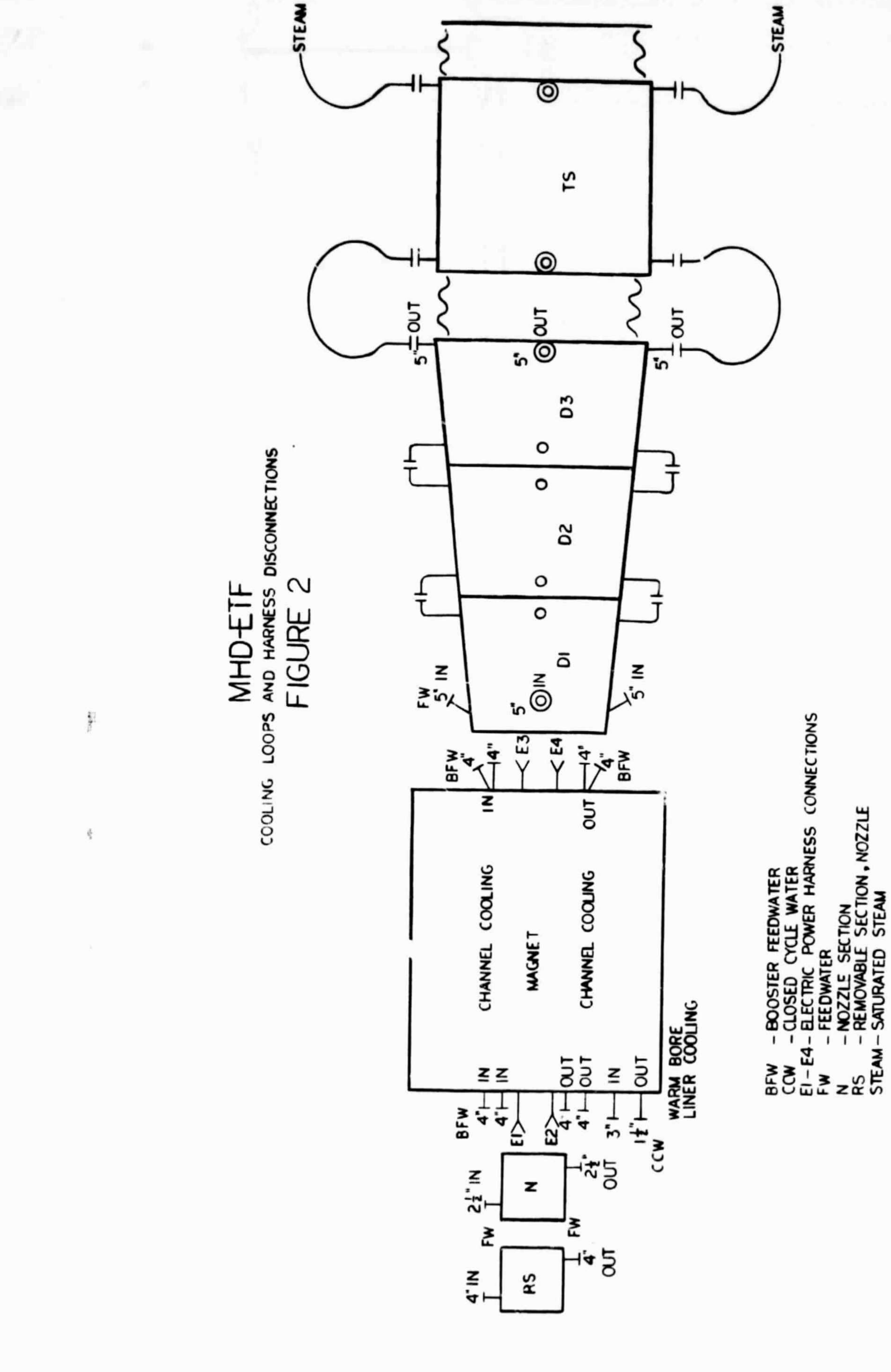
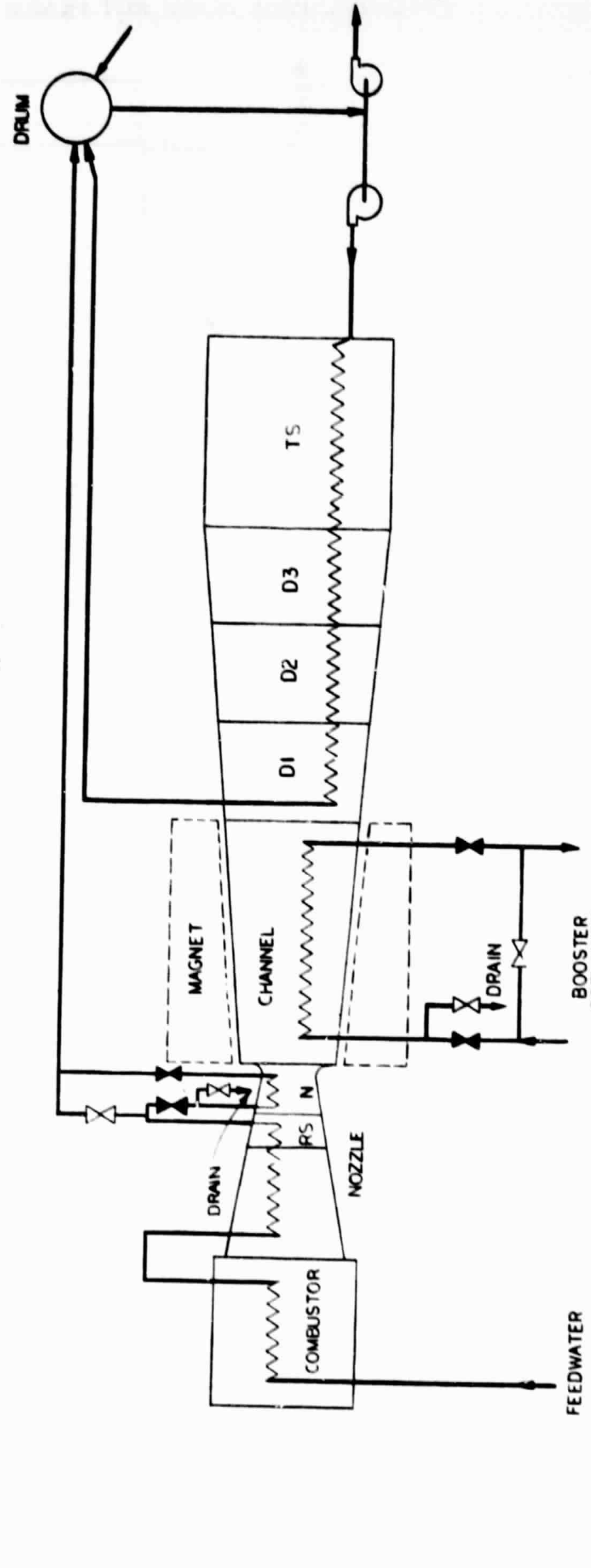
MHD-ETF
FIGURE 2
COOLING LOOPS AND HARNESS DISCONNECTIONS



MHD-ETF

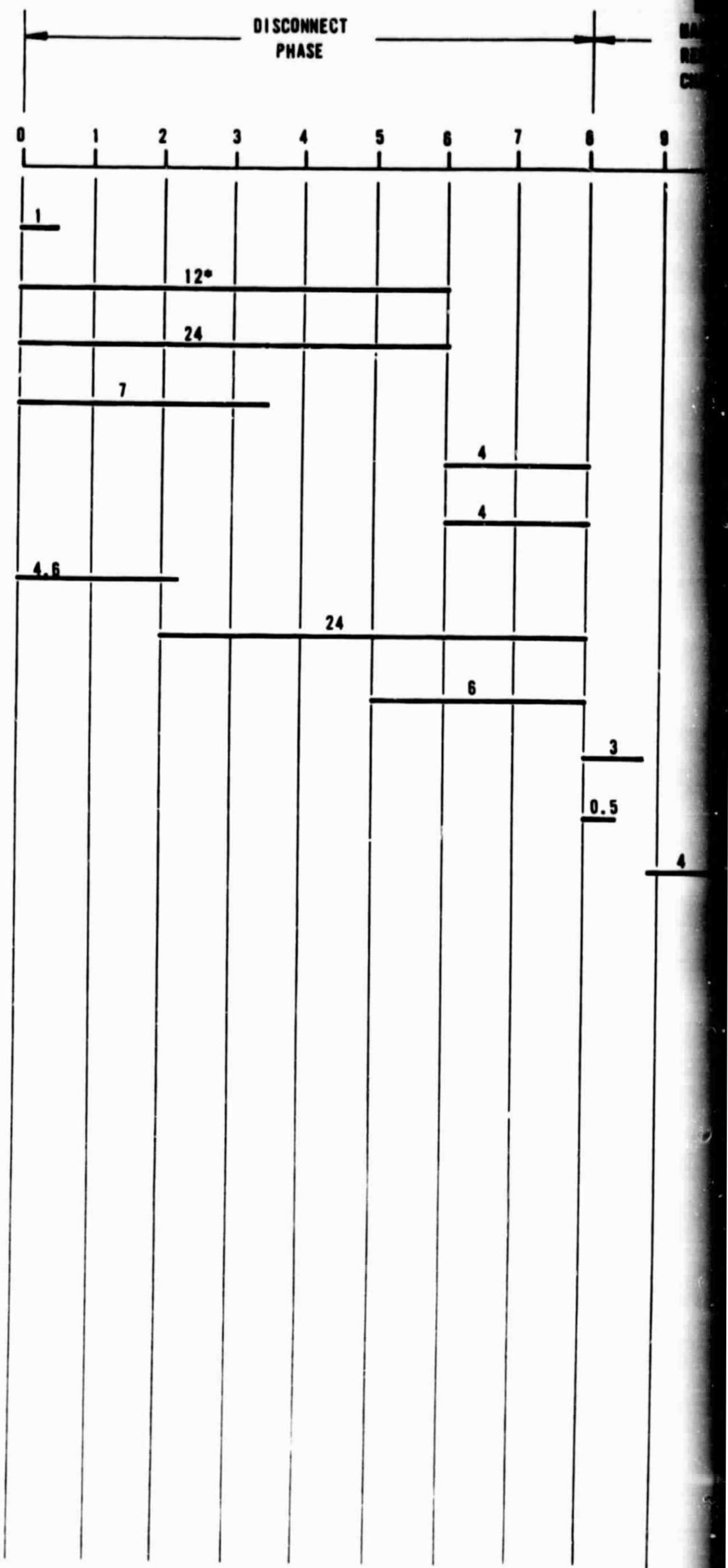
ROLL-ASIDE MAGNET BY-PASS CONNECTIONS AND VALVE LINE-UP

FIGURE 3



CHANNEL REPLACEMENT SEQUENCE-TASK NO. 306
ROLL-ASIDE MAGNET CONCEPT

CHRONOL...

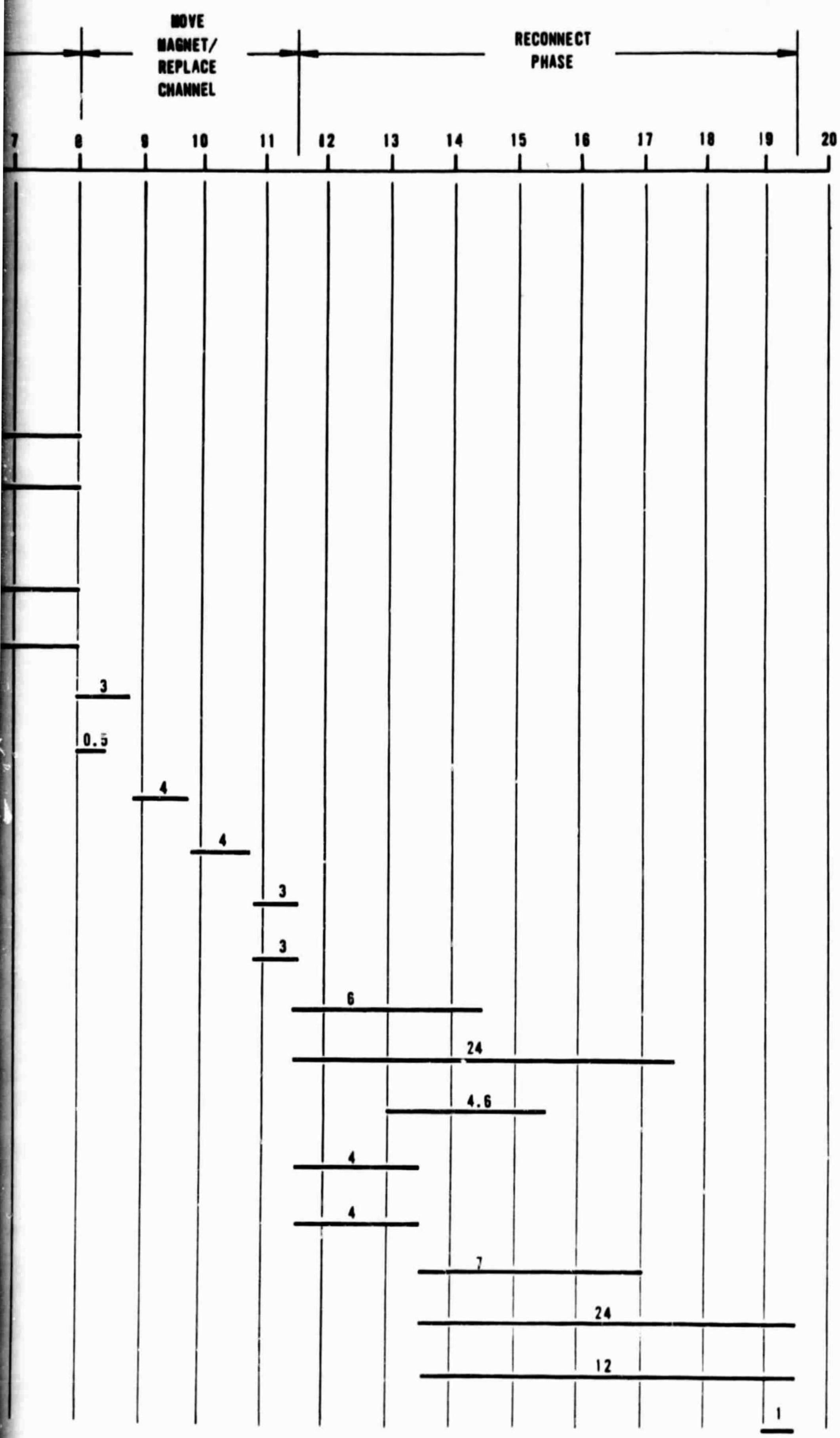


1. VENT AND DRAIN COMPONENT COOLING LINES
2. DISCONNECT NOZZLE COOLING FLANGES
3. DISCONNECT CHANNEL COOLING FLANGES (COMB. & DIFF. ENDS)
4. DISCONNECT CHANNEL/DIFFUSER FLANGE
5. DISCONNECT CHANNEL/NOZZLE FLANGE
6. DISCONNECT PLASMA DUCT/NOZZLE FLANGE
7. DISCONNECT MAGNET WARM BORE COOLING FLANGES
8. DISCONNECT ELECTRICAL CONNS. & REMOVE PIPING FROM MAGNET OUTLINE (COMB. & DIFF. ENDS)
9. DISCONNECT MAGNET FIXED SUPPORTS/SET MAGNET ON ROLLERS
10. MOVE MAGNET 34 FT. TO CHANNEL REPLACEMENT AREA (9"/MIN. AVG.)
11. POSITION CHANNEL TRANSFER FIXTURE
12. REMOVE DEFECTIVE CHANNEL
13. INSERT NEW OR REPAIRED CHANNEL
14. MOVE MAGNET BACK TO OPERATIONAL POSITION
15. DEFECTIVE CHANNEL HOISTED & TRANSFERRED TO RAIL CAR
16. SECURE MAGNET TO FIXED SUPPORTS
17. REASSEMBLE ELECTRICAL CONNECTIONS & INSTALL PIPING TO FLANGE CONNECTIONS (COMB. & DIFF. ENDS)
18. REASSEMBLE WARM BORE COOLING FLANGES
19. REASSEMBLE PLASMA DUCT/NOZZLE FLANGE
20. REASSEMBLE CHANNEL/NOZZLE FLANGE
21. REASSEMBLE CHANNEL/DIFFUSER FLANGE
22. CONNECT CHANNEL COOLING FLANGES (COMB. & DIFF. ENDS)
23. CONNECT NOZZLE COOLING FLANGES
24. REFILL COOLING LINES & CLOSE DRAIN & VENT VALVES

FOLDOUT FRAME /

* MANHOURS REQUIRED FOR EACH TASK

TABLE 1



FOLDOUT FRAME 2

Utility and pipefitter time standards for flange assemblies were:

Size	Rating	M-H
in.	lb.	
1-1/2	300	2.0
3	300	2.6
4	300	3.0
2-1/2	1,500	6.0
4	1,500	12.0
5	1,500	17.0

Rectangular ducting flanges were assigned 0.35 M-H for each bolt assembly. Total calendar time needed was 19.5 hours; total man-hours needed was 190.7. Two shutoff valves were incorporated in the bypass piping for both the high pressure and low pressure (channel) feedwater loops. One valve was used for bypass in each loop. The shutoff valves will be in the flow path during normal operation and contribute to line pressure drop.

During the mechanical dissassembly and assembly the magnet is kept cryogenically cooled. Continuous connection of piping and electrical leads to the magnet are provided at any magnet position by use of a utility boom.

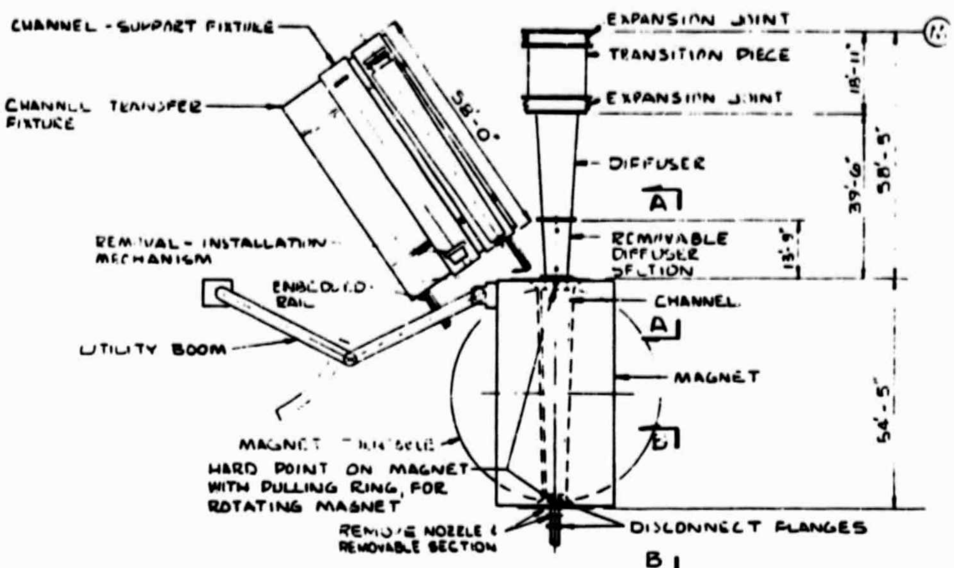
Rotated Magnet

The sequence for removing and replacing a channel utilizing a rotated magnet is illustrated in Drawing C-673-029. Bypass loops and valving are shown on Figure 4. A summary of the steps is presented in Table 2. To provide clearance to pivot the magnet 35°, the removable section/nozzle (RS)* and the first section of the diffuser assembly,(D1) had to be disconnected and removed. The 5" cooling pipe flanges to diffuser section D1, required 17 hours for each of 4 to disconnect and 24 hours to connect. Total calendar hours required was 33.0; man-hours was 490.7. Nozzle cooling water bypass moved upstream of (RS) and a bypass for the diffuser section,(D1) had to be added. Four high pressure valves and two low-pressure valves will be included in the feedwater cooling loop during normal operation.

Split Magnet

The sequences for removing and replacing a channel utilizing a split magnet are illustrated on Drawing C-673-031. Bypass loops and the associated valving are shown on Figure 5. A summary of sequences is on Table 3. Channel supports extend through slots in the magnet assembly and are in place while the magnet is in a separated position. No cradle is needed; the disconnected channel is hoisted vertically and then laterally, to avoid the double boom, to the rail car. Calendar time requirements are 16.5 hours with 155.2 man-hours of effort. Only channel bypass is required and only two low pressure valves will be added to the cooling circuit during normal operation. In addition, this alternate facilitates inspection of the channel and provides a potential for in-place repair.

* Bracketed designations are defined on Figure 1.



PLAN

STEP

(1) MAGNET IN OPERATING POSITION - REMOVE REMOVABLE DIFFUSER SECTION, NOZZLE AND REMOVABLE SECTION. REFER TO TABLE 2 CHANNEL REPLACEMENT SEQUENCE ROTATED MAGNET.

STEP

(2) MAGNET ... PLACE ... REFER TO T...

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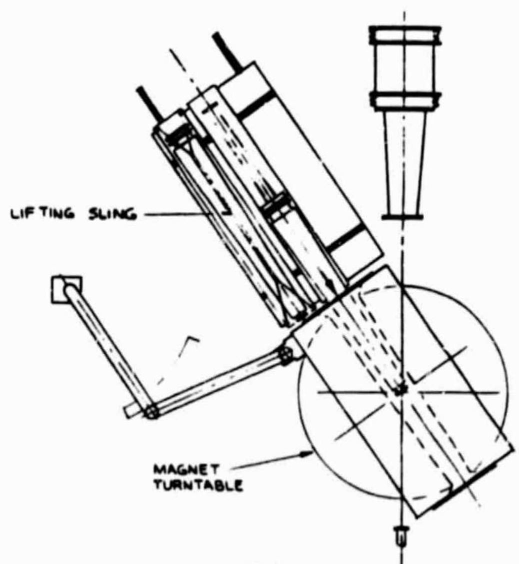
REFERENCE DRAWINGS

MHD BUILDING - 8270-1-310-010-001
MHD BUILDING - 8270-1-310-010-002



PLAN

UTILITY BOOM

STEP

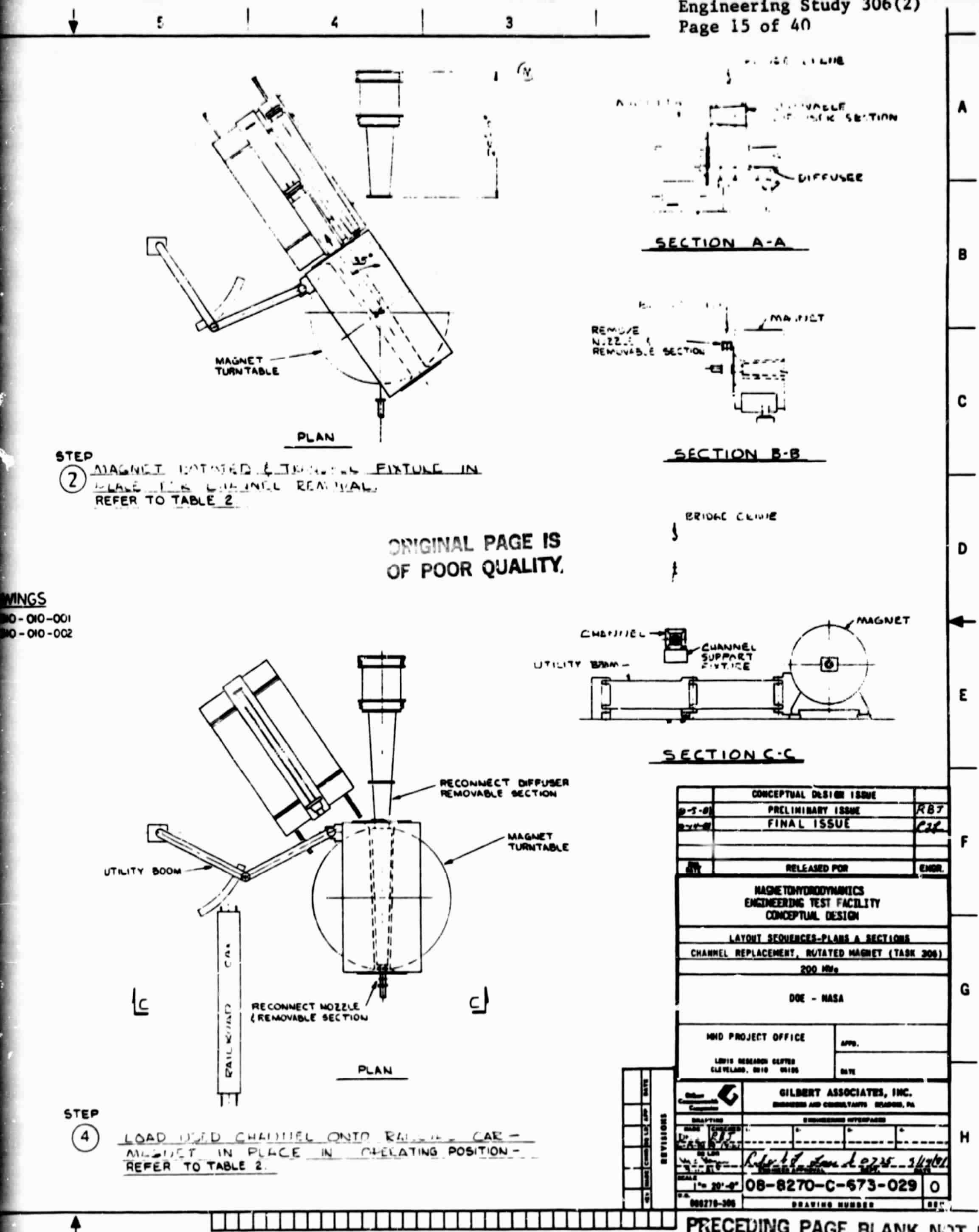
(3) TRANSFER FIXTURE IN PLACE ... INSERTION OF NEW CHANNEL - CONNECTION OF CRANE TO USED CHANNEL SUPPORT FIXTURE FOR LIFTING. REFER TO TABLE 2.

STEP

(4) LOAD ... REFER ...

FOLDOUT FRAME

1/8" = 1'-0" 0' 5' 10' 15' 20'


SECTION A-A
DIFFUSER
SECTION B-B
MAGNET
SECTION C-C
MAGNET
CHANNEL SUPPORT FIXTURE
MAGNET TURNTABLE
PLAN
STEP 2
REFER TO TABLE 2
RECONNECT DIFFUSER REMOVABLE SECTION
MAGNET TURNTABLE
UTILITY BOOM
RECONNECT NOZZLE (REMOVABLE SECTION
PLAN
STEP 4
REFER TO TABLE 2.
CONCEPTUAL DESIGN ISSUE
PRELIMINARY ISSUE
FINAL ISSUE
RELEASED FOR
MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN
LAYOUT SEQUENCES-PLANS & SECTIONS
CHANNEL REPLACEMENT, ROTATED MAGNET (TASK 306)
200 MWe
DOE - NASA
MHD PROJECT OFFICE
GILBERT ASSOCIATES, INC.
08-8270-C-673-029
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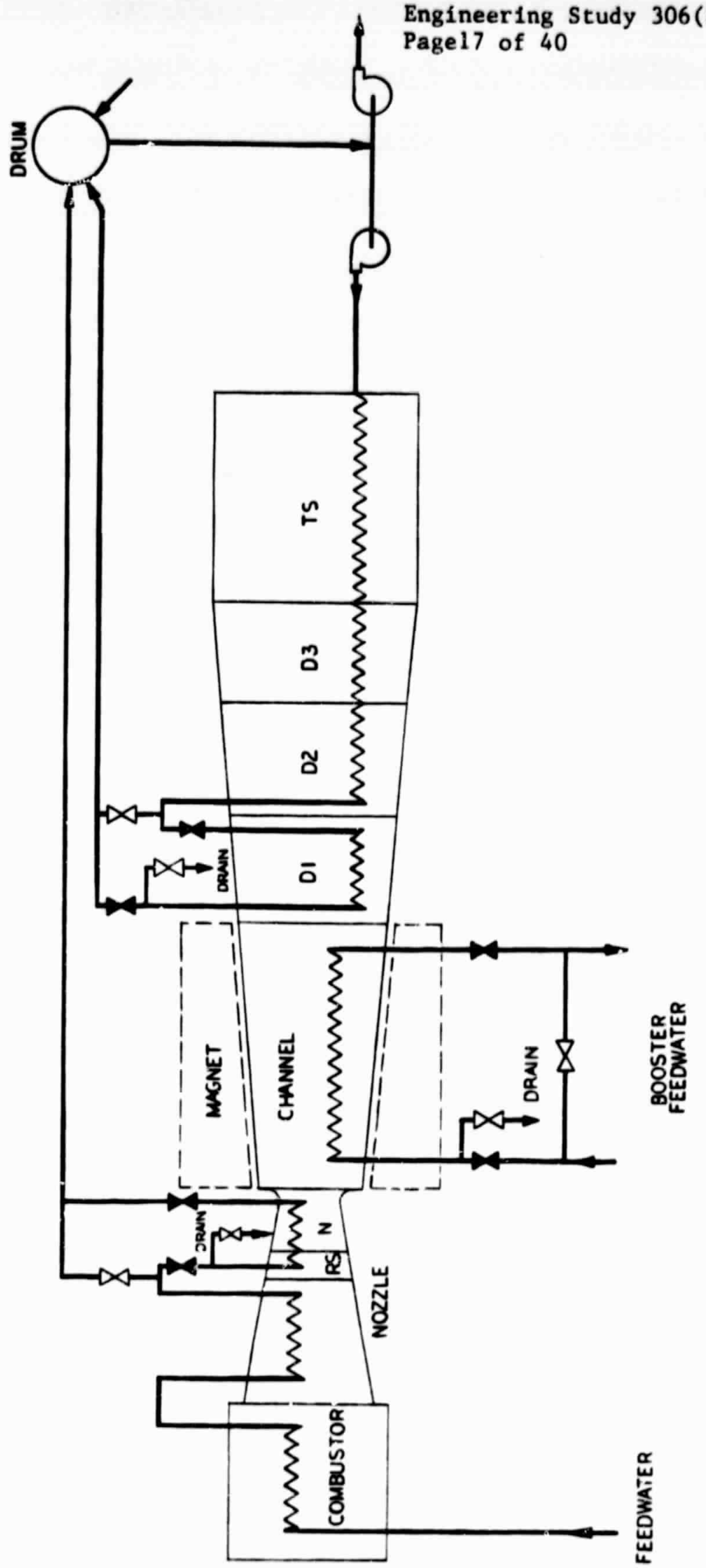
REVISIONS



MHD-ETF
ROTATED MAGNET BY-PASS CONNECTIONS AND VALVE LINE-UP
FIGURE 4

CHANNEL REPLACEMENT SEQUENCE–TASK NO. 306
ROTATED MAGNET CONCEPT

CHRONOLOGICA

* MANHOURS REQUIRED FOR EACH TASK

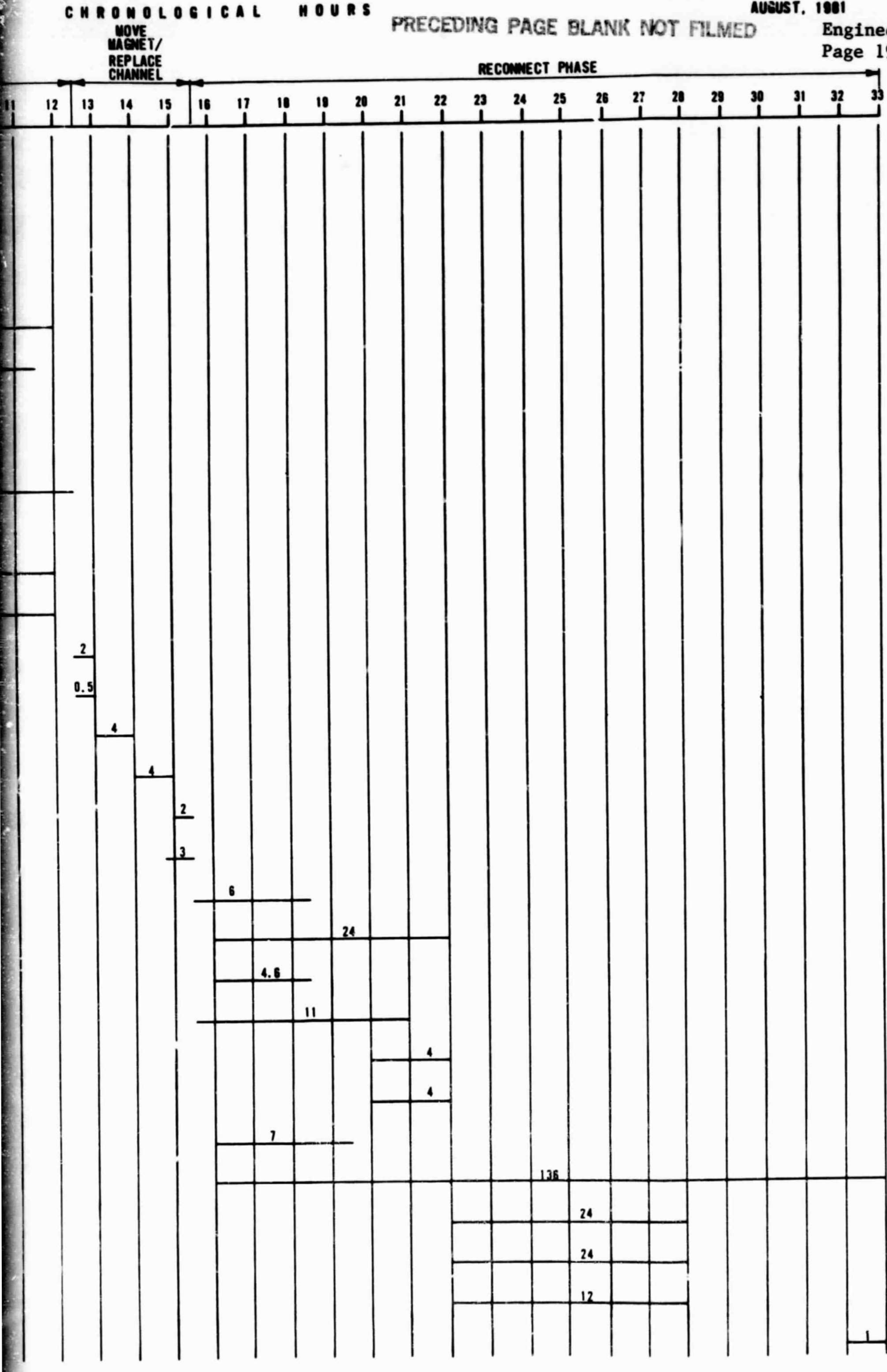
DISCONNECT PHASE (0–12) | MOVE MAGNET/ REPLACE CHANNEL (12–15.5)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Task	Manhours*
1. VENT AND DRAIN COMPONENT COOLING LINES	1
2. DISCONNECT NOZZLE COOLING FLANGES	12*
3. DISCONNECT REMOVABLE NOZZLE SECTION COOLING FLANGES	24
4. DISCONNECT CHANNEL COOLING FLANGES (COMB. & DIFF. ENDS)	24
5. DISCONNECT DIFFUSER COOLING FLANGES (FIRST SECTION OF DIFFUSER)	96
6. DISCONNECT CHANNEL/DIFFUSER FLANGE	7
7. DISCONNECT CHANNEL/NOZZLE FLANGE	4
8. DISCONNECT REMOVABLE SECTION/NOZZLE FLANGE	4
9. DISCONNECT DIFFUSER SECTION FLANGE AND REMOVE FIRST SECTION OF DIFFUSER	11
10. DISCONNECT MAGNET WARM BORE COOLING FLANGES	4.6
11. DISCONNECT ELECTRICAL CONNS. & REMOVE PIPING FROM MAGNET OUTLINE (COMB. & DIFF. ENDS)	24
12. DISCONNECT MAGNET FIXED SUPPORTS/SET MAGNET ON ROTATING SUPPORT PLATFORM	6
13. ROTATE MAGNET 35°	2
14. POSITION CHANNEL TRANSFER FIXTURE	0.5
15. REMOVE CHANNEL	4
16. INSERT REPLACEMENT CHANNEL	4
17. ROTATE MAGNET BACK 35°	2
18. REPLACED CHANNEL HOISTED AND TRANSFERRED TO RAIL CAR	3
19. SECURE MAGNET TO FIXED SUPPORTS	6
20. CONNECT ELECTRICAL CONNECTIONS AND INSTALL PIPING TO FLANGE CONNECTS (COMB. AND DIFF. ENDS)	
21. CONNECT WARM BORE COOLING FLANGES	
22. CONNECT DIFFUSER SECTION FLANGE	
23. CONNECT REMOVABLE SECTION/NOZZLE FLANGE	
24. CONNECT CHANNEL/NOZZLE FLANGE	
25. CONNECT CHANNEL/DIFFUSER FLANGE	
26. CONNECT DIFFUSER COOLING FLANGES (FIRST SECTION OF DIFFUSER)	
27. CONNECT CHANNEL COOLING FLANGES (COMB. AND DIFF. ENDS)	
28. CONNECT REMOVABLE NOZZLE SECTION COOLING FLANGES	
29. CONNECT NOZZLE COOLING FLANGES	
30. REFILL COOLING LINES AND CLOSE DRAIN AND VENT VALVES	

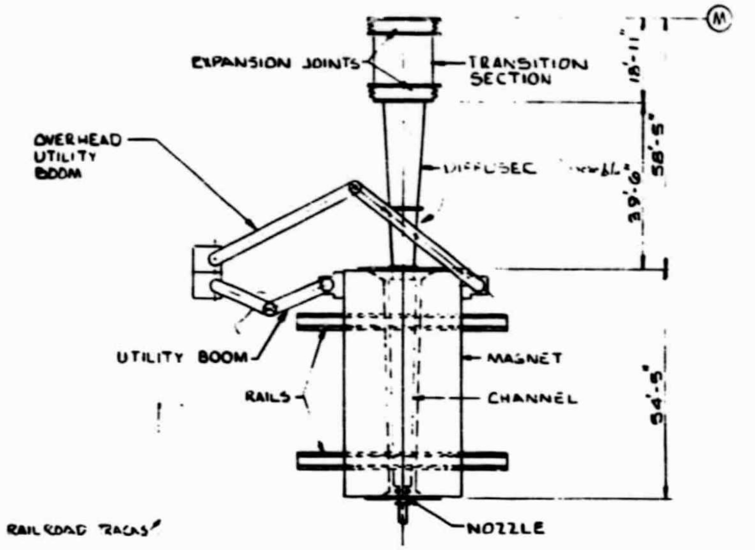
FOLDOUT FRAME

TABLE 2

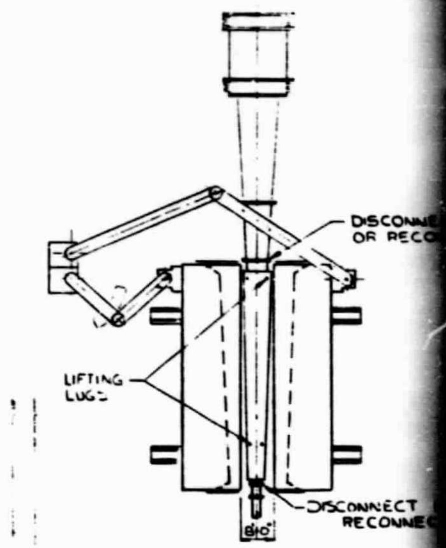


FOLDOUT FRAME 2

10 9 8 7 6 5



PLAN

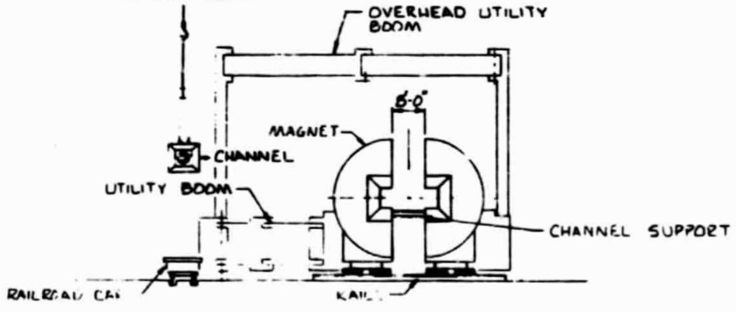


PLAN

STEPS
① & ⑥ CHANNEL IN OPERATING POSITION.
REFER TO TABLE 3, CHANNEL REPLACEMENT SEQUENCE SPLIT MAGNET.

STEP ② SPLIT MAGNET FOR CHANNEL REM
DISCONNECT FLANGES. REFER TO TA

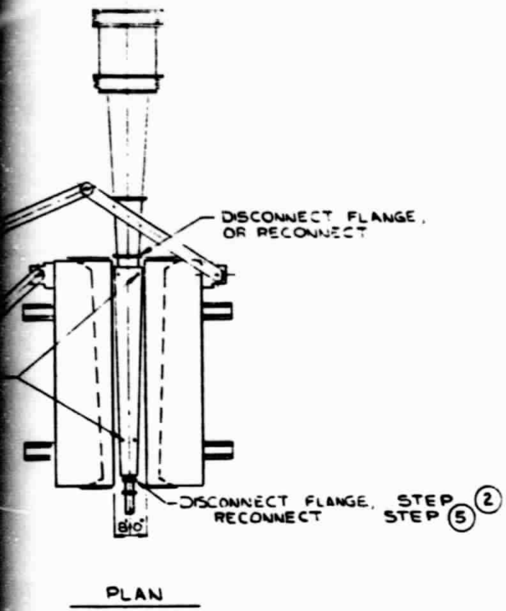
STEP ⑤ INSERT NEW CHANNEL & RECONNEC
FLANGES. REFER TO TABLE 3.

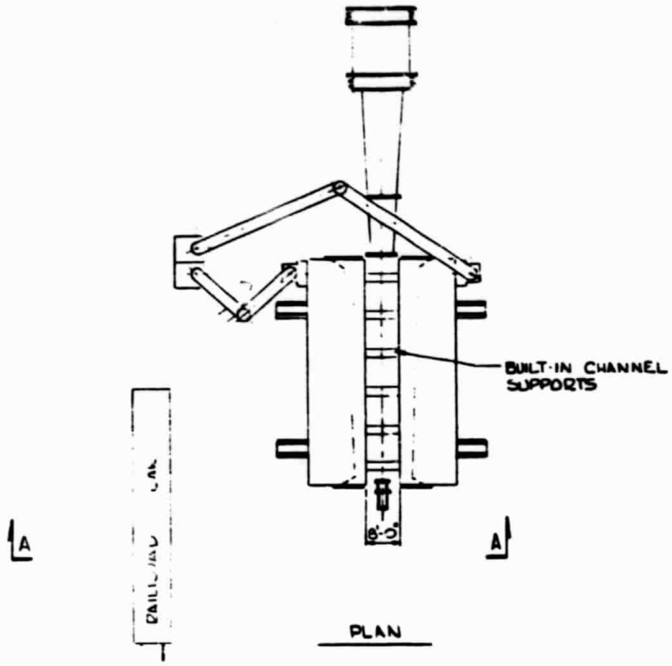


SECTION "A-A"

FOLDOUT FRAME

¼" = 1'-0" 0' 5' 10' 15' 20'





MAGNET FOR CHANNEL REMOVAL
ECT FLANGES. REFER TO TABLE 3.
NEW CHANNEL & RECONNECT
5. REFER TO TABLE 3.

STEP ③ REMOVE USED CHANNEL & LOAD ONTO RAILROAD CAR. REFER TO TABLE 3.

STEP ④ REMOVE NEW CHANNEL FROM STORAGE CRADLE. REFER TO TABLE 3.

REFERENCE DRAWINGS

MHD BUILDING - 8270 - 1 - 310 - 010 - 001
MHD BUILDING - 8270 - 1 - 310 - 010 - 002

	CONCEPTUAL DESIGN ISSUE	
8-5-81	PRELIMINARY ISSUE	RBJ
5-14-81	FINAL ISSUE	
	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

LAYOUT SEQUENCES-PLANS & SECTION
CHANNEL REPLACEMENT, SPLIT MAGNET (TASK 306)
200 MWE

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD.
DATE

REVISIONS

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING
ENGINEERING INTERFACES
DN: RBJ

SCALE 1" = 20'-0"

08-8270-C-673-031 REV 0

DRAWING NUMBER

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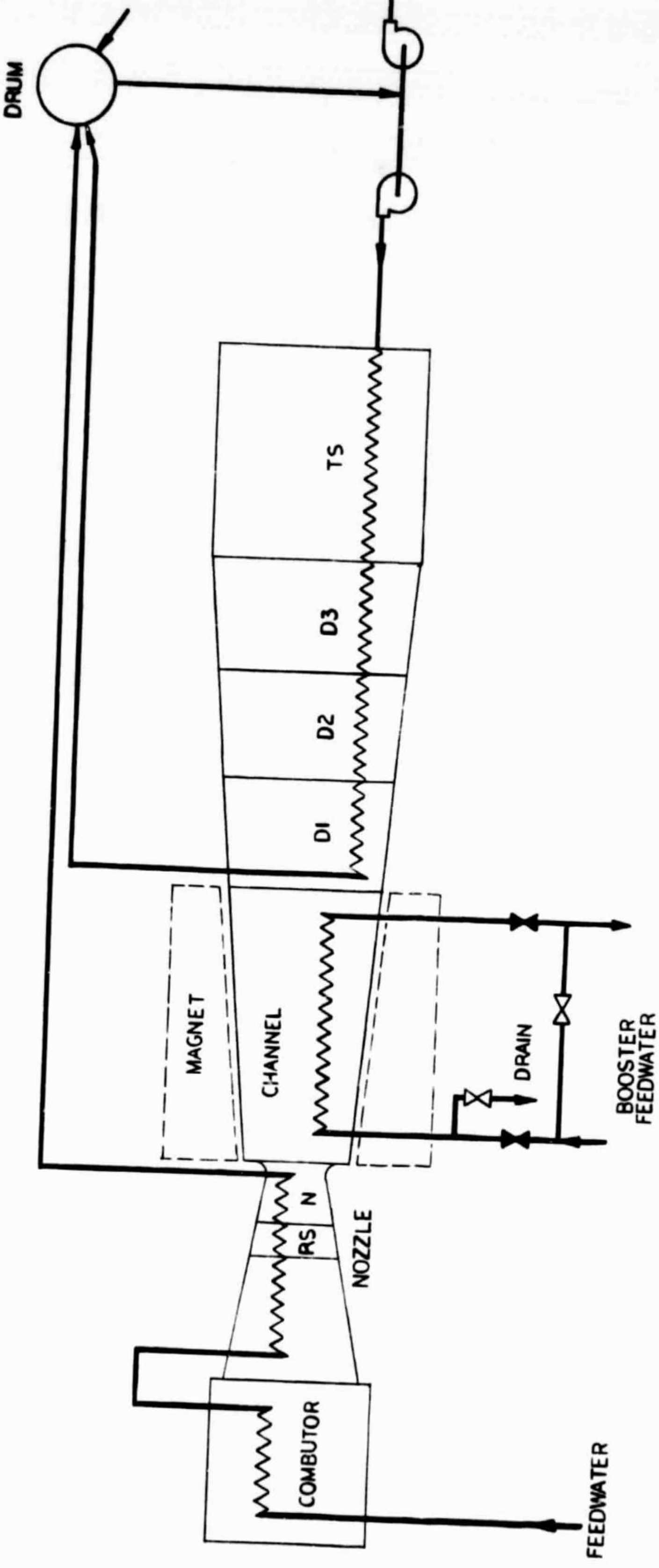
MHD-ETF

SPLIT MAGNET BY-PASS CONNECTIONS AND VALVE LINE-UP

FIGURE 5

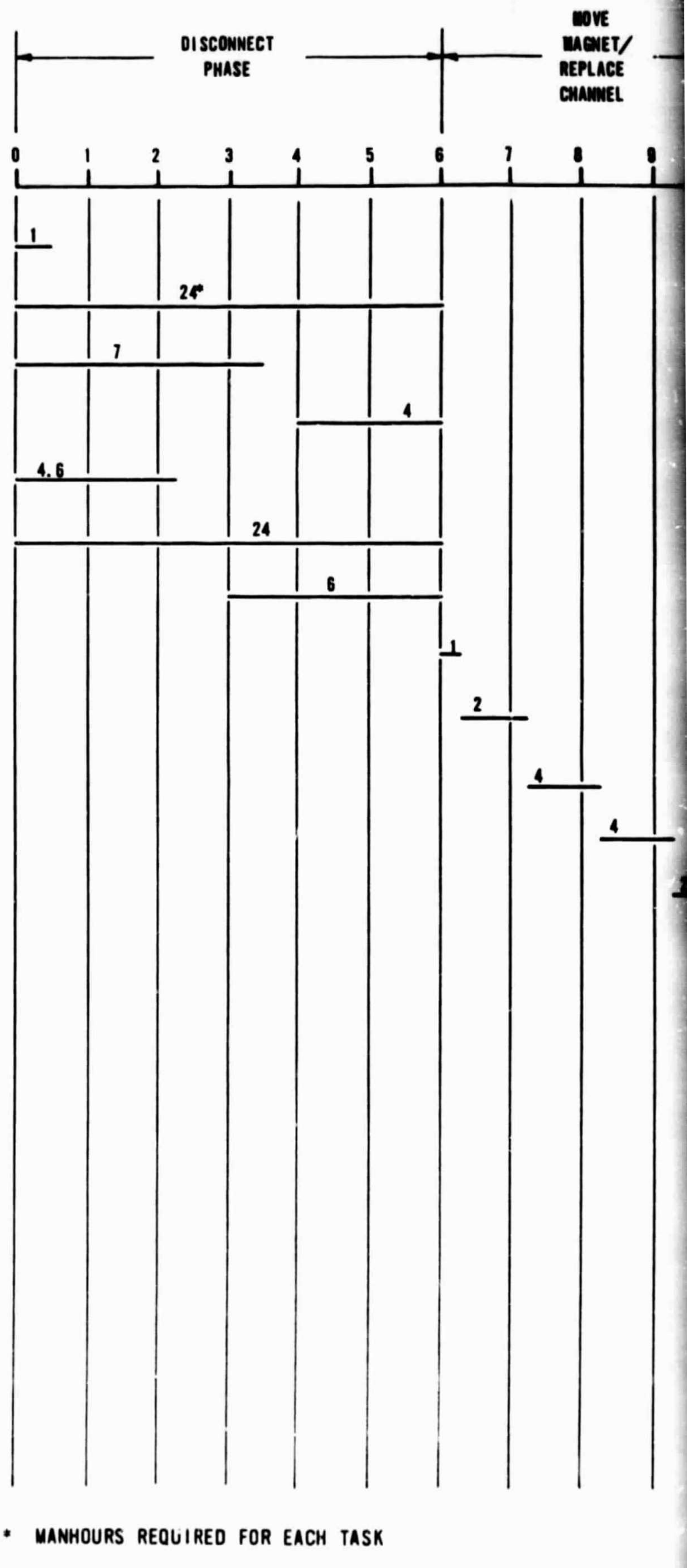


CHANNEL REPLACEMENT SEQUENCE-TASK NO. 306
SPLIT MAGNET CONCEPT

CHRONOLOGICAL HO

FOLDOUT FRAME

1. VENT AND DRAIN COMPONENT COOLING LINES
2. DISCONNECT CHANNEL COOLING FLANGES (COMB. & DIFF. ENDS)
3. DISCONNECT CHANNEL/DIFFUSER FLANGE
4. DISCONNECT CHANNEL/NOZZLE FLANGE
5. DISCONNECT MAGNET WARM BORE COOLING FLANGES
6. DISCONNECT ELECTRICAL CONNS. & REMOVE PIPING FROM MAGNET OUTLINE (COMB. & DIFF. ENDS)
7. DISCONNECT MAGNET FIXED SUPPORTS/SET MAGNET ON ROLLERS
8. MOVE SPLIT SECTIONS OF MAGNET
9. DISCONNECT CHANNEL FROM SUPPORTS
10. REMOVE CHANNEL
11. INSERT NEW REPLACEMENT CHANNEL
12. CONNECT CHANNEL TO SUPPORTS
13. MOVE MAGNET SECTIONS BACK TO OPERATIONAL POSITION
14. SECURE MAGNET TO FIXED SUPPORTS
15. CONNECT ELECTRICAL CONNECTIONS & INSTALL PIPING TO FLANGE CONNECTIONS (COMB. & DIFF. ENDS)
16. CONNECT WARM BORE COOLING FLANGES
17. CONNECT CHANNEL/NOZZLE FLANGE
18. CONNECT CHANNEL/DIFFUSER FLANGE
19. CONNECT CHANNEL COOLING FLANGES (COMB. & DIFF. ENDS)
20. REFILL COOLING LINES & CLOSE DRAIN & VENT VALVES



* MANHOURS REQUIRED FOR EACH TASK

CHRONOLOGICAL HOURS AUGUST, 1981

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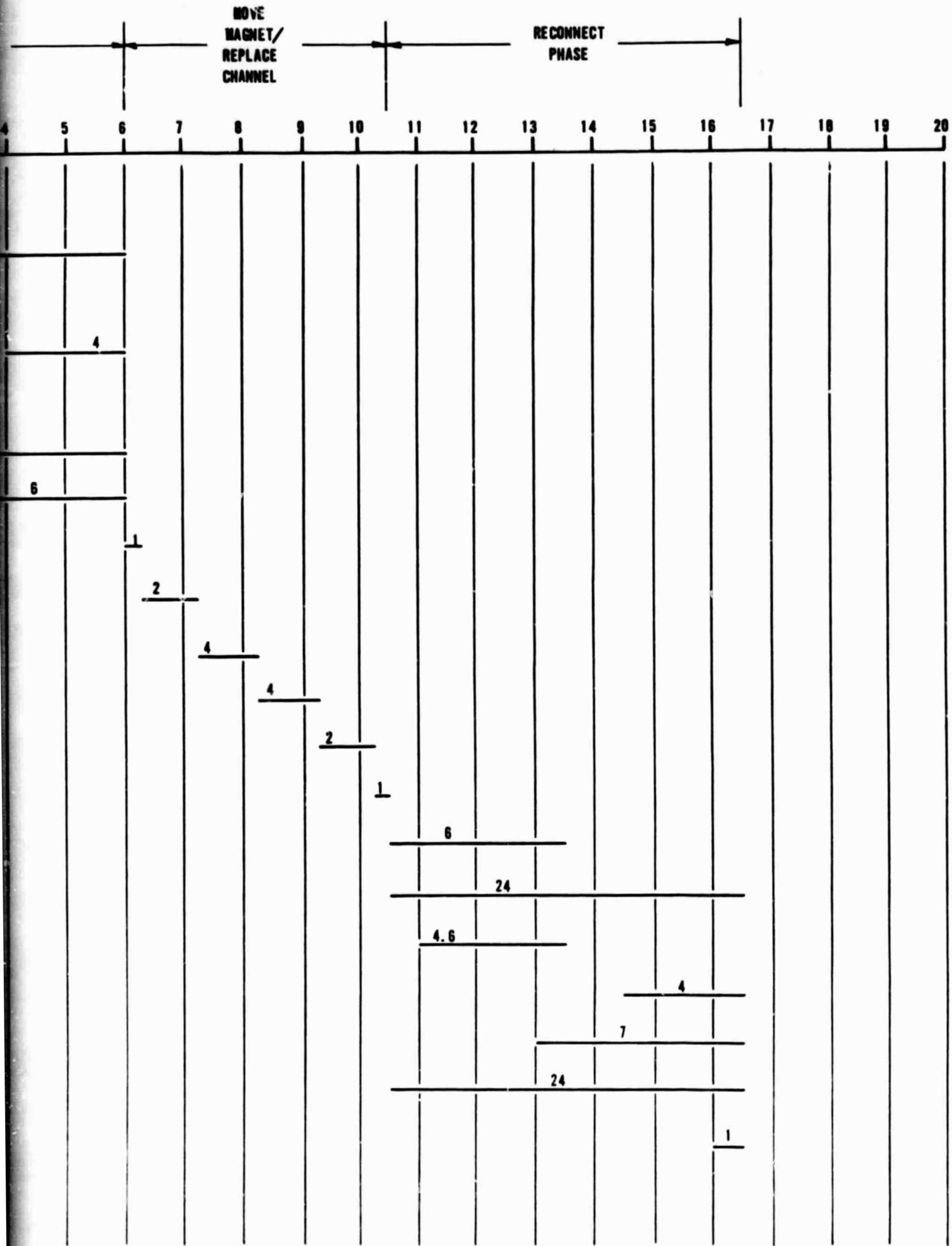
TABLE 3



CH TASK

Fixed Magnet

The channel can be removed without disturbance of the magnet by removing the diffuser,(D1, D2, D3) and transition section,(TS) to provide clearance for channel pull. Sequences are illustrated on Drawing C-673-028. Associated bypass piping and valving are shown on Figure 6. Removal of the nozzle section,(N) provides space for pulleys and accessory fixtures used in pulling and replacing the channel. Mechanics of channel replacement takes 32 hours and requires 426.7 man-hours. A summary of steps is provided on Table 4.

The bypass system requires 6 high pressure and 3 low pressure valves. Four high pressure and two low pressure valves are in the feedwater flow circuit during normal operation.

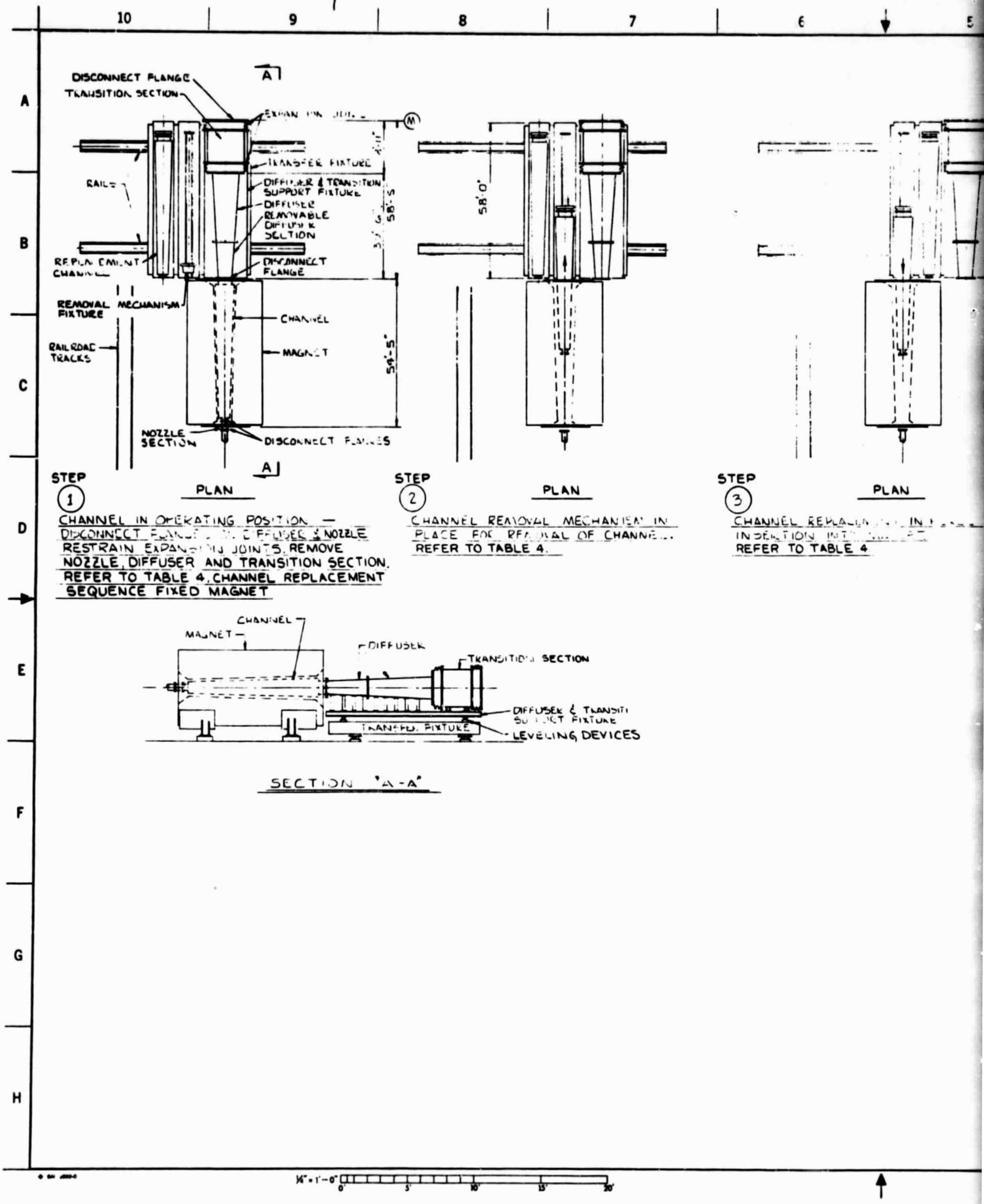
No booms are required for the magnet, which is undisturbed. The channel cradle can be moved to abut with the rail car to transfer the spent channel since there is no blockage. Hoisting of the channel is eliminated. Pull length is tight since the boiler house structural wall, 58' - 5" from the channel upstream flange, leaves only 5' - 11" total clearance for cradle and pull equipment. If a fixed magnet were selected, subsystem and structural arrangements could be modified, as needed, to better accommodate channel replacement.

Cooldown and Subsequent Startup

The magnet arrangement and techniques used to replace a failed channel will have negligible effects on the power reduction and cooldown of the power loops and the subsequent startup. Critical features during the cooling and heating transients will be temperature gradients from top to bottom of the boiler drum and temperature differences through the drum wall.

For both cooling, during shutdown, and heating, during startup, for the nominal 6 inch thick drum, top to bottom allowable temperature differential was 100°F. For steam pressure ratings of 1,900 psi, corresponding drum wall temperature difference allowables were 85°F for cooling and 205°F for heating. This is shown in Figure 7. The allowable heating rate of the feedwater during startup is 80°F an hour as shown on Figure 8. In about 7-1/2 hours, drum water temperatures will be brought from 150°F to 630°F. If the resistance ratio, $\frac{k}{r_m h}$, approaches zero, the inner surface follows the same temperature profile as the feedwater in contact with it. For high heat transfer coefficient, h, as occurs with water as a flow medium, the approximation is valid and conservative, for normal values of conductivity, k, and wall thickness, r_m. Table 5 tabulates boiler drum parameters during the startup heating. The critical point occurs at the fourth hour with a ΔT of 160°F* through the drum wall, but with top to bottom gradients at their limit. The analysis is, of course, general. Specific calculations require details of the boiler actually in service.

* Note this includes the effects of top to bottom gradients and fluid temperature differentials since recovery of surface temperature at the back surface at the same location is relatively rapid (about 1 hour).


10
9
8
7
6
5
A
B
C
D
E
F
G
H
DISCONNECT FLANGE
TRANSITION SECTION
TRANSFER FIXTURE
DIFFUSER & TRANSITION SUPPORT FIXTURE
DIFFUSER
REMOVABLE DIFFUSER SECTION
DISCONNECT FLANGE
RAILS
REPLACEMENT CHANNEL
REMOVAL MECHANISM FIXTURE
RAILROAD TRACKS
CHANNEL
MAGNET
NOZZLE SECTION
DISCONNECT FLANGES
58'-0"
54'-5"
STEP 1
PLAN
CHANNEL IN OPERATING POSITION — DISCONNECT FLANGES ... DIFFUSER & NOZZLE RESTRAIN EXPANSION JOINTS, REMOVE NOZZLE, DIFFUSER AND TRANSITION SECTION. REFER TO TABLE 4, CHANNEL REPLACEMENT SEQUENCE FIXED MAGNET
STEP 2
PLAN
CHANNEL REMOVAL MECHANISM IN PLACE FOR REMOVAL OF CHANNEL. REFER TO TABLE 4.
STEP 3
PLAN
REFER TO TABLE 4
CHANNEL
MAGNET
DIFFUSER
TRANSITION SECTION
DIFFUSER & TRANSITION SUPPORT FIXTURE
TRANSFER FIXTURE
LEVELING DEVICES
SECTION "A-A"
1/4" = 1'-0"
0'
5'
10'
15'
20'

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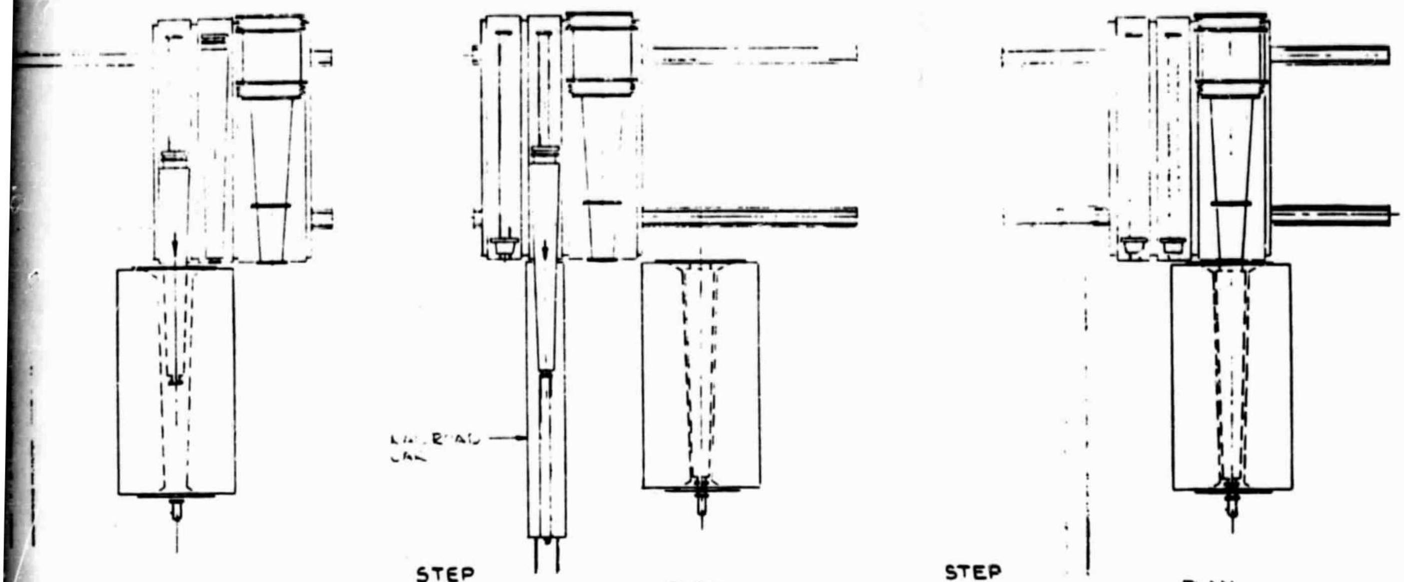

REPLACEMENT ... IN ... ON INTO ... TO TABLE 4

STEP 4: USED CHANNEL MOVED ... LOADING ONTO RAILROAD CAR & NOZZLE SECTION RECONNECTED REFER TO TABLE 4

STEP 5: DIFFUSER & TRANSITION SUPPORT FIXTURE MOVED INTO OPERATING POSITION & DIFFUSER AND TRANSITION SECTION RECONNECTED. REFER TO TABLE 4.

REFERENCE DRAWINGS

MHD BUILDING - 8270-1-310-010-001
MHD BUILDING - 8270-1-310-010-002

	CONCEPTUAL DESIGN ISSUE	
8-5-81	PRELIMINARY ISSUE	RBJ
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ISSUE	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

LAYOUT SEQUENCES-PLANS & SECTION
CHANNEL REPLACEMENT, FIXED MAGNET (TASK 306)
200 MWe

DOE - NASA

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LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

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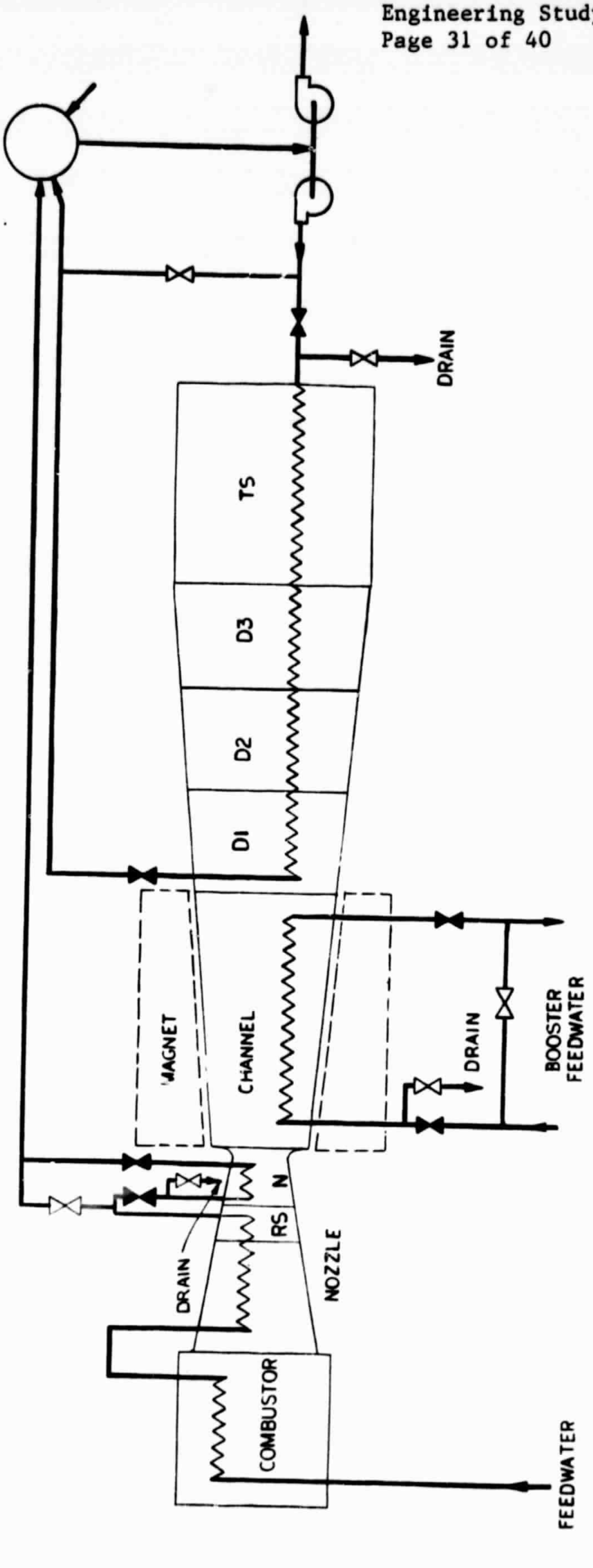
08-8270-C-673-028
REV 0
DRAWING NUMBER
G.O. 008270-306



MHD-ETF
FIXED MAGNET BY-PASS CONNECTIONS AND VALVE LINE-UP
FIGURE 6

FOLDOUT FRAME

CHANNEL REPLACEMENT SEQUENCE
TASK NO. 306
FIXED MAGNET CONCEPT

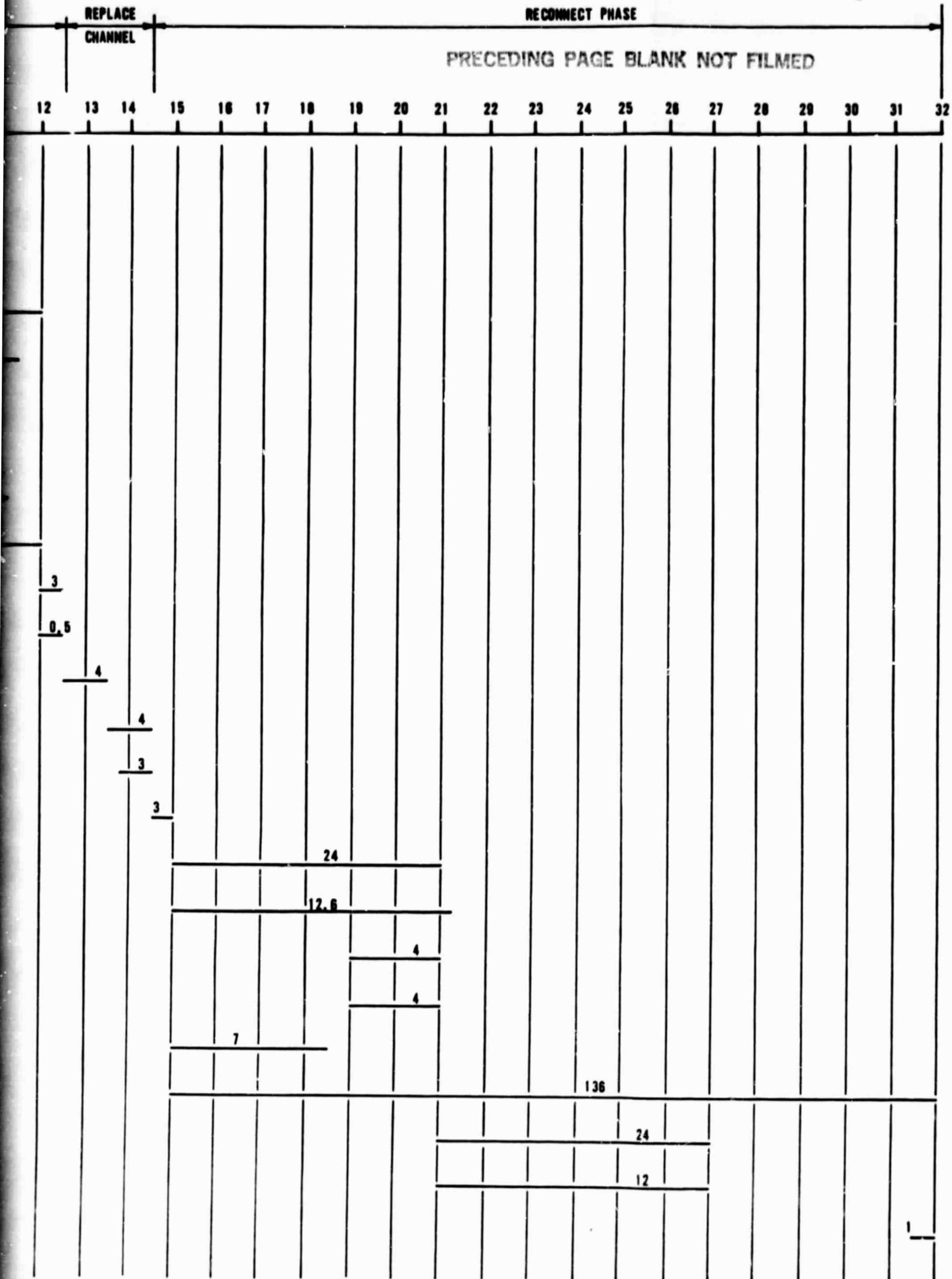
DISCONNECT PHASE | REPLACE CHANNEL

Time scale: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

No.	Task	Manhours
1.	VENT AND DRAIN COMPONENT COOLING LINES	1
2.	DISCONNECT NOZZLE COOLING FLANGES	12*
3.	DISCONNECT CHANNEL COOLING FLANGES (COMB. AND DIFF. ENDS)	24
4.	DISCONNECT DIFFUSER/TRANSITION ASSEMBLY COOLING FLANGES	96
5.	DISCONNECT CHANNEL/DIFFUSER FLANGE	7
6.	DISCONNECT CHANNEL/NOZZLE FLANGE	4
7.	DISCONNECT PLASMA DUCT/NOZZLE FLANGE	4
8.	DISCONNECT TRANSITION SECTION/HR/SR FLANGE	12.6
9.	DISCONNECT ELECTRICAL CONNS. AND REMOVE PIPING FROM MAGNET OUTLINE (COMB. AND DIFF. ENDS)	24
10.	REMOVE AND STORE DIFFUSER/TRANSITION ASSEMBLY	3
11.	POSITION CHANNEL TRANSFER FIXTURE	3.5
12.	REMOVE CHANNEL	4
13.	INSERT NEW REPLACEMENT CHANNEL	4
14.	REPLACED CHANNEL TRANSFERRED TO RAIL CAR	3
15.	DIFFUSER/TRANSITION ASSEMBLY PLACED IN OPERATIONAL POSITION	
16.	CONNECT ELECTRICAL CONNS. AND INSTALL PIPING TO FLANGE CONNS. (COMB. AND DIFF. ENDS)	
17.	CONNECT TRANSITION SECTION/HR/SR FLANGE	
18.	CONNECT PLASMA DUCT/NOZZLE FLANGE	
19.	CONNECT CHANNEL/NOZZLE FLANGE	
20.	CONNECT CHANNEL/DIFFUSER FLANGE	
21.	CONNECT DIFFUSER/TRANSITION ASSEMBLY COOLING FLANGES	
22.	CONNECT CHANNEL COOLING FLANGES (COMB. AND DIFF. ENDS)	
23.	CONNECT NOZZLE COOLING FLANGES	
24.	REFILL COOLING LINES AND CLOSE DRAIN AND VENT VALVES	

* MANHOURS REQUIRED FOR EACH TASK

TABLE 4


REPLACE CHANNEL
RECONNECT PHASE
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
3
0.5
4
4
3
3
24
12.6
4
4
7
136
24
12
1

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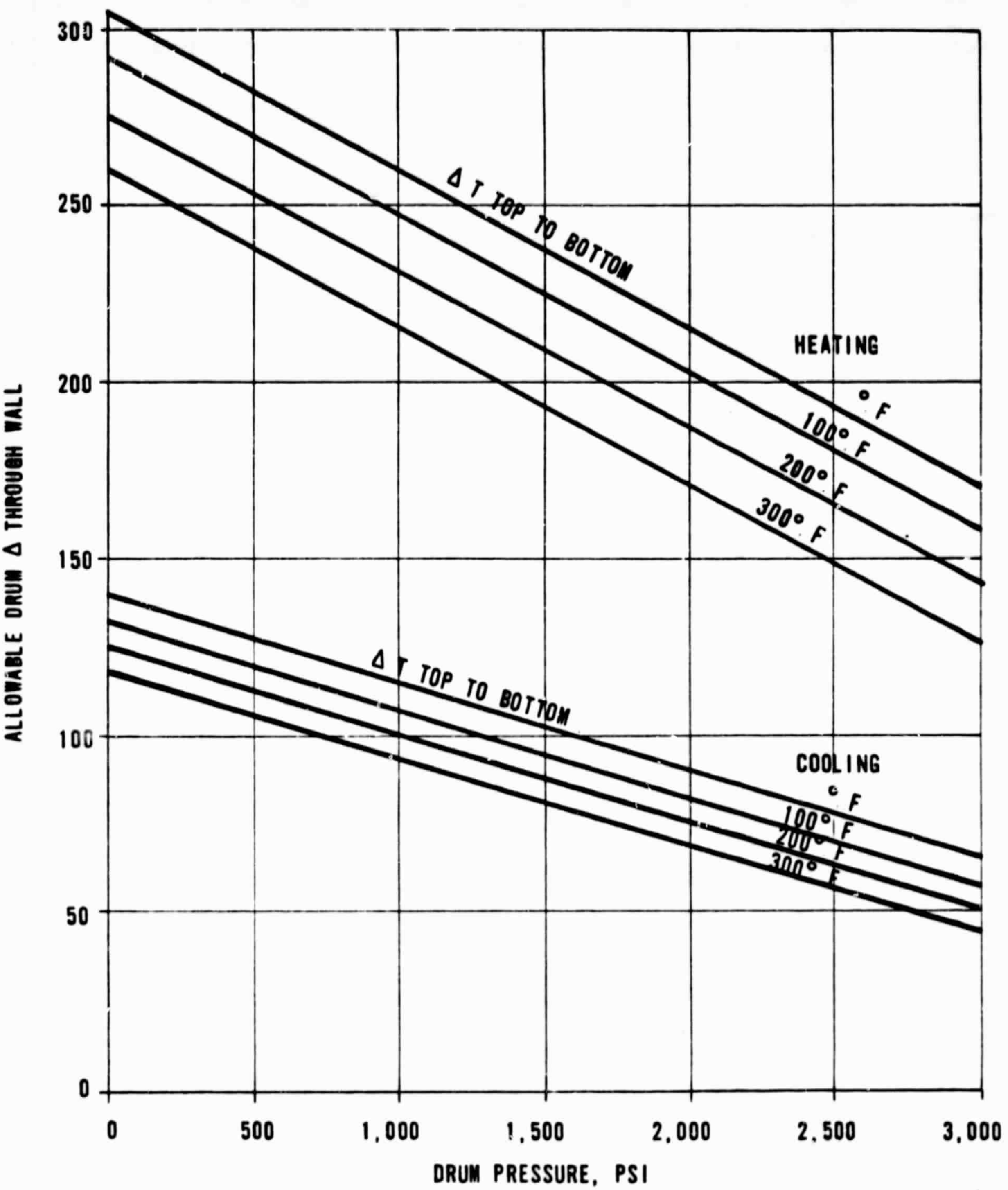

FIGURE 7
ALLOWABLE TEMPERATURE DIFFERENTIAL LIMITS FOR STEAM DRUM

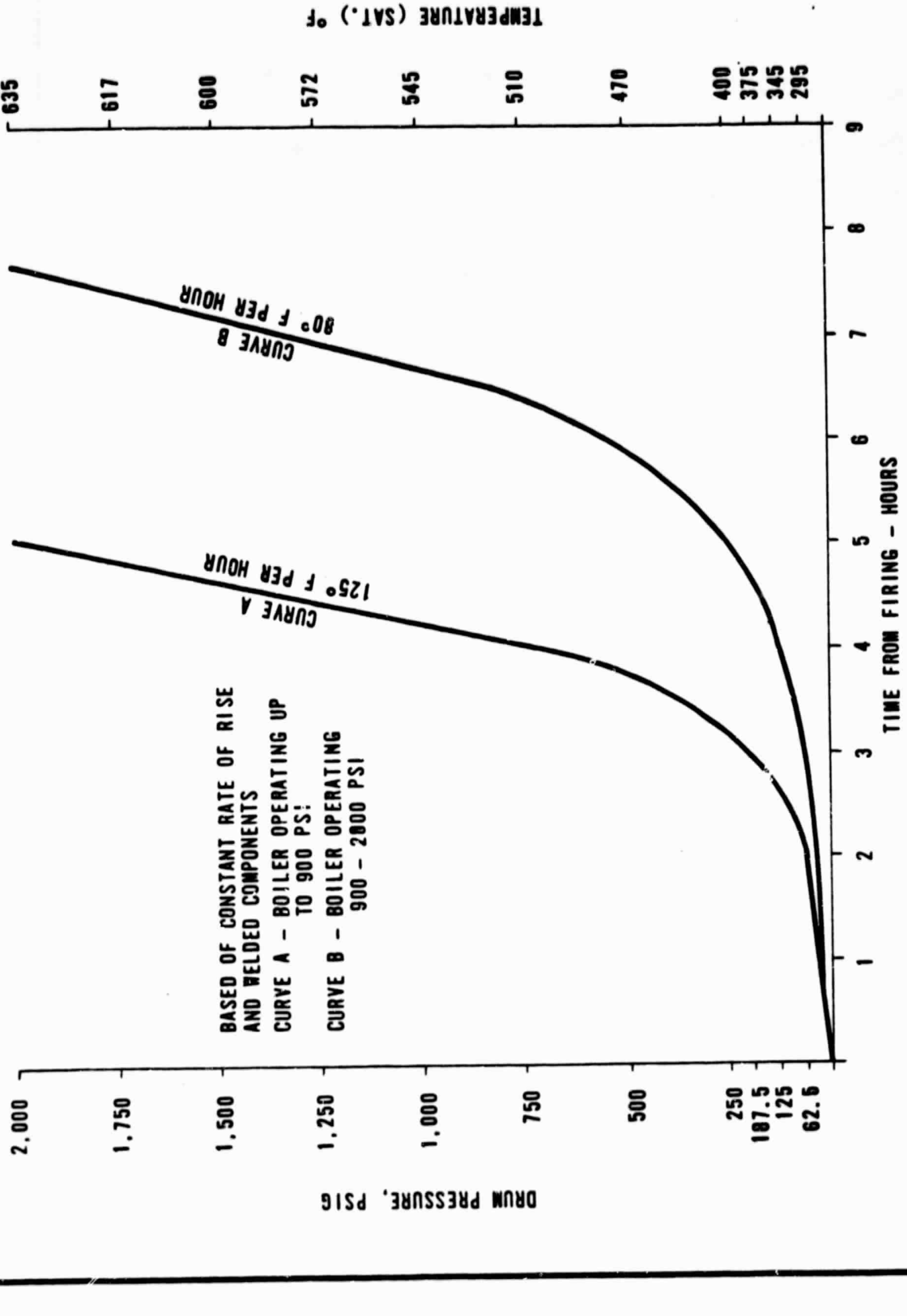

FIGURE 8
HEATING CURVE FOR DRUM BOILERS

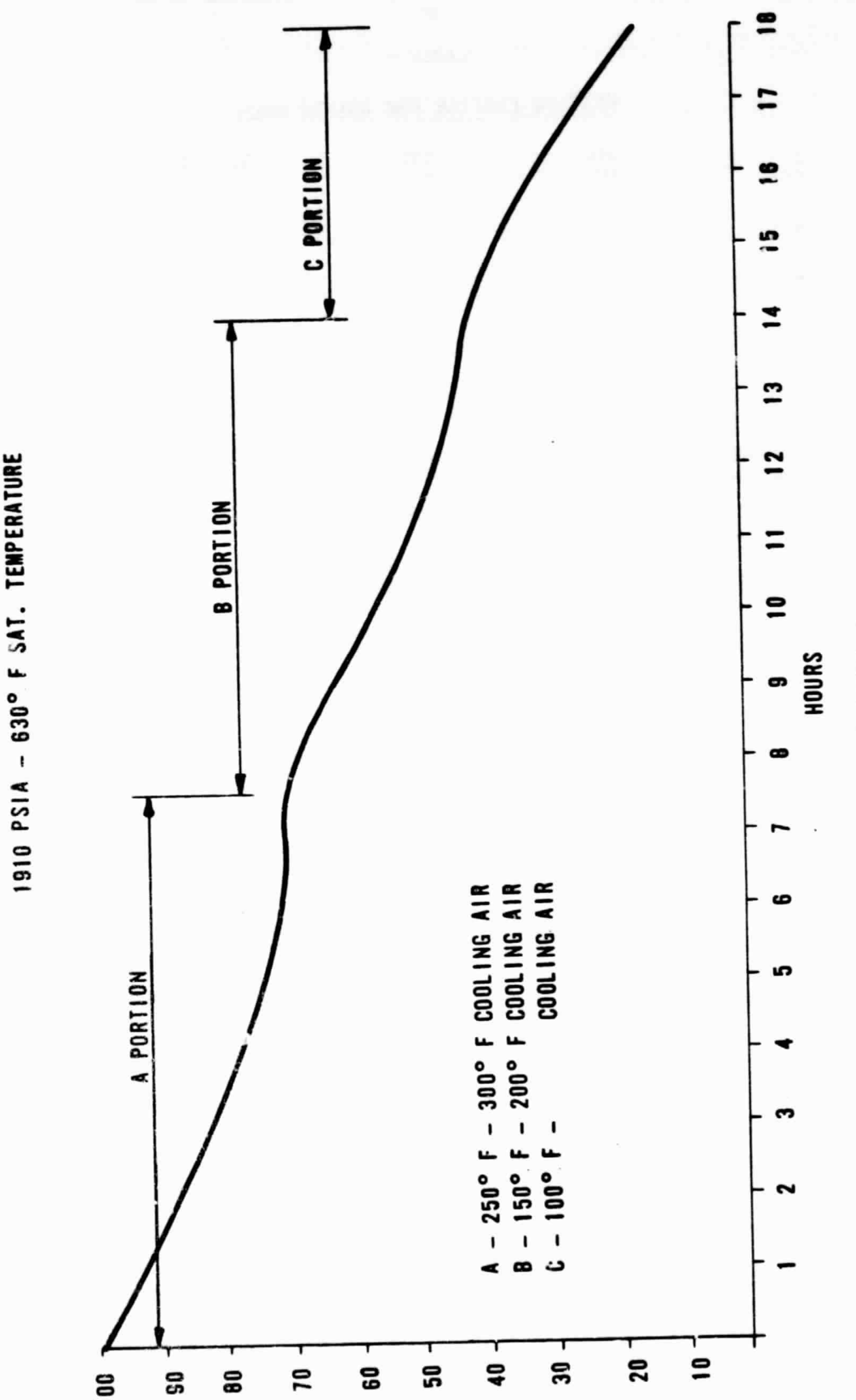

FIGURE 9
RADIANT BOILER COOLING CURVE FORCED DRAFT COOLING

TABLE 5

HEATING PROFILE FOR BOILER DRUM

t hr	ΔTs °F	ΔTb °F	Ts - Tb °F
0	0	0	0
1	80	0	80
2	160	28	132
3	240	88	152
4	320	160	160
6	450	350	100
8	480	430	50

t = time from start
ΔTs = temperature change of inner drum surface
ΔTb = temperature change of back surface
Ts - Tb = temperature difference through drum

Recovery factors stay the same for the drum during shutoff and cooldown. Table 6 shows the pertinent parameters of the drum during a 15 hour cooling cycle. Maximum rate of change of feedwater temperature is 40°F per hour. Also draft air fanning occurs as shown on Figure 9.

TABLE 6

COOLING PROFILE FOR BOILER DRUM

t-hr	ΔTs-°F	ΔTb-°F	Ts-Tb-°F
0	0		0
1	-40	0	40
2	-80	-14	66
3	-120	-44	76
4	-160	-80	80
6	-240	-187	53
8	-320	-288	32
10	-400	-380	20
15	-480	-446	0

t = time from start
ΔTs = temperature change of inner drum surface
ΔTb = temperature change of back surface
Ts-Tb = temperature difference through the drum

Air is supplied during the critical cooldown phase of the first 7 to 8 hours at 250 to 300°F, when temperature differences at the inner and outer drum surfaces are near their limit. During the intermediate phase, of 5 to 7 hours, air is at 150° to 200°F, and in the final phase at 100°F. This last temperature is also the assumed ambient, 100°F. Fanning air will also help

cool down the topping side. Because of the large cooling surface and thinner sections, the topping side can take larger gradients and will not be a limiting factor.

Figure 10 shows gradients through the drum wall for shutdown and startup considered typical for the ETF configuration. Total cooldown time to start of channel replacement is 15 hours. Total startup to full load time duration, after replacement of channel in operating position, is 10.5 hours. The shutdown and startup time of 25.5 hours is additive to the time for the channel replacement cycle regardless of which alternative for replacement is selected. For the reference concept total outage time to replace the channel is 45 hours.

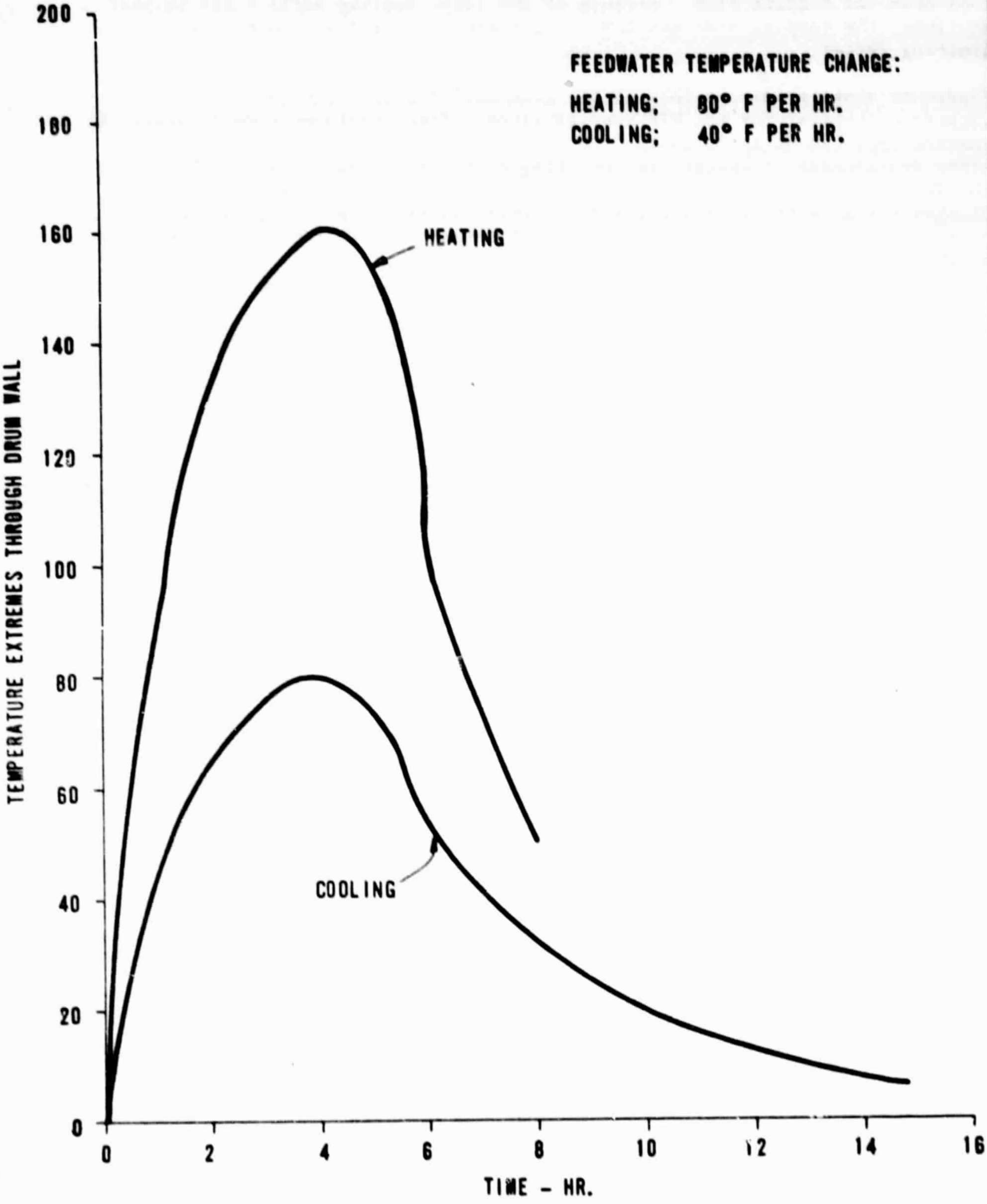

FIGURE 10
GRADIENT EXTREMES THROUGH BOILER DRUM WALL DURING SHUTDOWN AND STARTUP

GAI Ref. No. 091-429-307
Engineering Study 307

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 307

REGENERATIVE COMBUSTOR COOLING

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

GILBERT ASSOCIATES, INC.
P.O. BOX 1498
READING, PA. 19603

SEPTEMBER 1981

TITLE: Regenerative Combustor Cooling

SCOPE:

An analytical evaluation was made to determine the impact on the ETF performance, layout, and configuration of utilizing the combustor and nozzle heat losses to preheat the oxidant, and thereby eliminate the Intermediate Temperature Oxidant Heater (ITOH) and the related high temperature oxidant lines between the Heat Recovery/Seed Recovery System (HR/SR) and the Combustor.

FINDINGS:

The use of a regenerative combustor and the elimination of the ITOH results in only minor changes to the reference (CDER) ETF plant layout. The ETF configuration and layout is simplified to a slight degree by (1) the elimination of the high temperature oxidant lines from the HR/SR Building, and (2) the deletion of the flue gas recirculation fans which are no longer required. However, the use of the selected regenerative combustor scheme requires (1) the addition of a liquid to gas (oxidant) closed-loop heat exchanger for transferring the combustor second stage and nozzle heat loads to the oxidant, (2) a slightly larger channel, and (3) a slightly modified diffuser to match the new channel operating conditions. Some changes in the HR/SR envelope dimensions are expected because of the significant changes in heat transfer areas for several HR/SR components. Other minor changes to the ETF configuration and layout include a slightly larger turbine-generator (5.7 percent increase in power output), a smaller electrostatic precipitator (7.8 percent decrease in capacity), and the possible addition of a feedwater heater upstream of the deaerator.

The use of a regenerative combustor for oxidant preheat to 778^{o}F causes only a slight reduction in overall plant performance. Net power output is reduced by 3.4 MWe to 198.9 MWe and plant efficiency is decreased by 0.64 points to 37.39 percent. The reduction in the MHD Generator power output of 11 MWe is partially offset by the increase in secondary side (steam cycle) power output of 7.3 MWe.

RECOMMENDATIONS:

Further study is required to evaluate the total economic impact of regenerative combustor cooling on the ETF design. A fairly detailed investigation will be required to establish the cost of a regenerative combustor specifically designed for the MHD-ETF plant. A comprehensive cost investigation will be required for the HR/SR because of the elimination of the ITOH plus changes in heat transfer areas for several HR/SR components.

Assuming favorable economic and risk evaluations it is recommended that the concept of a regenerative combustor for preheating the oxidant and thereby eliminating the ITOH be incorporated into the ETF plant design. This change is recommended because it simplifies the plant design with only a slight performance penalty. As shown in Figure 1, the selected regenerative combustor scheme is designed to preheat the oxidant to 778^{o}F by utilizing the total heat rejected by the combustor and nozzle walls. It is also recommended that a feedwater heater be added upstream of the deaerator in order to obtain a slight improvement in cycle efficiency and also establish a lower and more conventional value for the temperature rise across the deaerator.

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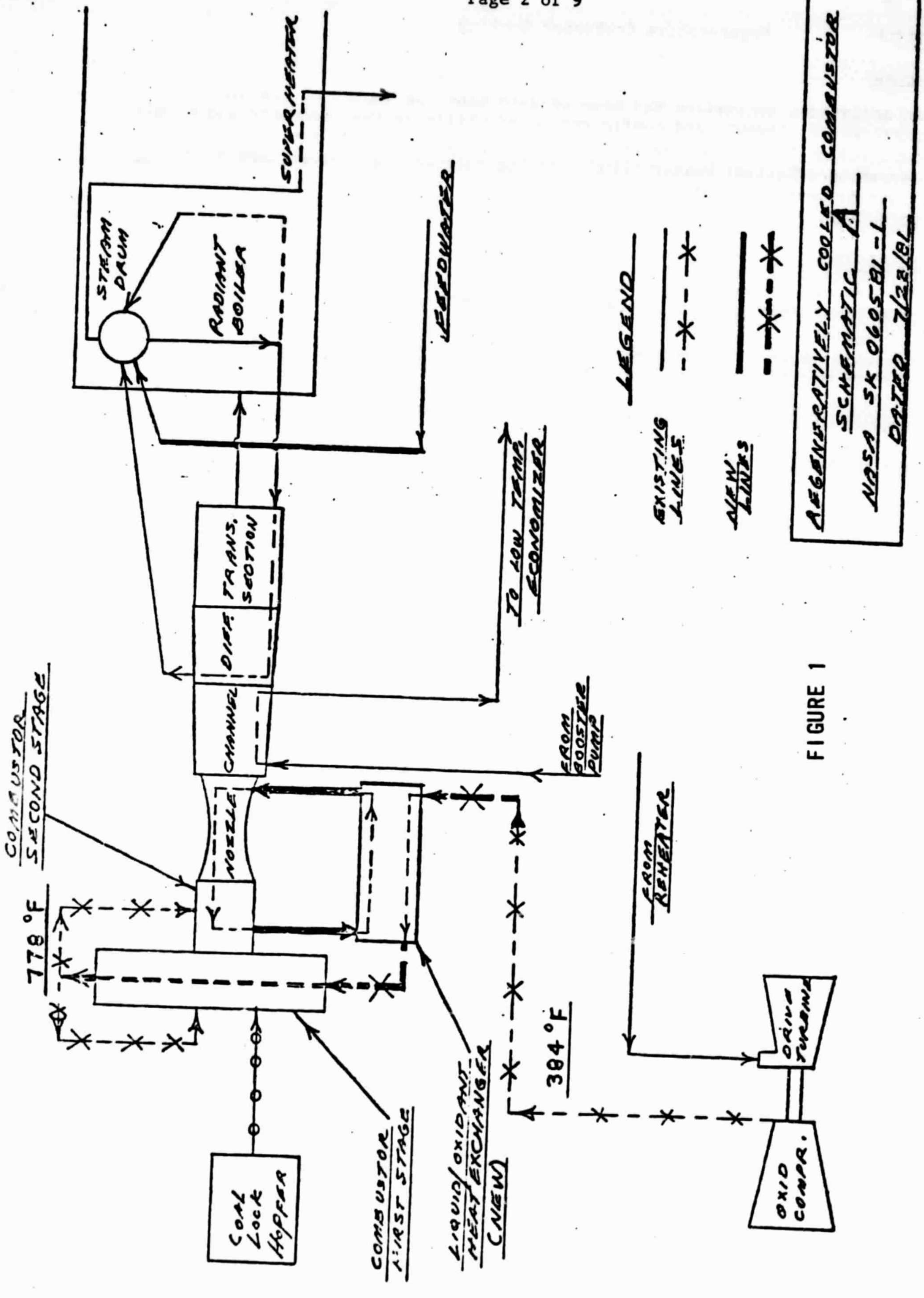

FIGURE 1

PROCEDURE:

The performance of the MHD-ETF plant was analytically evaluated to determine the impact on the ETF design of using a regenerative combustor to preheat the oxidant and thereby eliminate the Intermediate Temperature Oxidant Heater. For the selected regenerative combustor cooling scheme, it is assumed that the two stage TRW combustor has the capability of heating the oxidant and the total heat rejected by the combustor and nozzle is used to heat the oxidant. A liquid to gas (oxidant) closed loop heat exchanger system is required to transfer the heat load from the combustor second stage and nozzle to the oxidant. Additional heat is transferred directly to the oxidant in the combustor first stage tube wells and this establishes the final oxidant preheat temperature for the high temperature combustor process.

Computer-assisted calculations were used to determine the new oxidant preheat temperature and balanced conditions for mass flow and heat transfer were established for both the topping and bottoming side systems. The revised system heat and mass balance for regenerative combustor cooling was evaluated with respect to the following task objectives:

1) Identification of major state point changes.

2) Indentification of major system and equipment changes.

3) Sizing of liquid to gas (oxidant) heat exchanger.

4) Impact of proposed oxidant heating system on the ETF configuration and layout.

5) Identification of the advantages and disadvantages of regenerative combustor cooling relative to simplification of the ETF configuration and layout.

DISCUSSION:

A major concern associated with ETF plant reliability is the use of a recuperative heat exchanger in the HR/SR for preheating the oxidant prior to its delivery to the combustor. The tubes of this heat exchanger, the ITOH, are subjected to the severe environment of 1600°F flue gas temperatures and the erosive and corrosive flow of the seed-laden flue gas. The ITOH presents complex design problems since its operating environment imposes severe problems impacting both reliability and plant availability. During normal operation, the tubes of this gas heat exchanger are the hottest metal in the HR/SR in contact with the seed-laden flue gas. The elimination of the ITOH would simplify the ETF design and allow for greater ease of plant operation.

This study evaluates the use of a regenerative combustor for preheating the oxidant with the resultant elimination of the ITOH and the high temperature oxidant lines between the HR/SR and the combustor. For the selected regenerative combustor cooling scheme, the total heat rejected by the combustor and nozzle tube walls is used to preheat the oxidant. As shown in Figure 1, initial preheating of the oxidant is accomplished using a liquid

couple in which a secondary closed loop heat exchanger is used to transfer the heat from the combustor second stage and nozzle walls to the oxidant. Final preheating of the oxidant is then achieved by directing the oxidant flow through the combustor first stage cooling walls. For the CDER baseload design point, an estimated total of 24.84 MW of heat is transferred from the combustor and nozzle walls to the boiler feedwater. For this study, the boiler feedwater is replaced in the combustor first stage cooling jacket by oxidant cooling, and it is assumed that the same combustor and nozzle are used to preheat the oxidant. The total heat rejection rate of 24.84 MWe from the combustor and nozzle preheats the oxidant to 778°F prior to its delivery to the combustor for the high temperature combustion process.

Balanced conditions for mass flow and heat transfer for the oxidant preheat of 778°F were established for both the topping and bottoming side systems using computer-assisted calculations. These calculations produced an overall heat and mass balance that shows only a slight reduction in overall plant performance. Net power output is reduced from 202.2 to 198.9 MWe and plant efficiency is decreased from 38.0 to 37.4 percent. The ETF system power summary for this study is presented in Table 1.

The elimination of the ITOH and the regenerative heating of the oxidant to 778°F resulted in other system changes that affect both the topping and bottoming sides of the ETF plant. The lower oxidant preheat temperature results in reduced channel power output (by 11 MWe) because of the lower combustion temperature. This requires a lower channel expansion ratio and, therefore, a lower combustion pressure. This loss is partially recovered by the 1.8% or 7.5 MW additional heat input to the bottoming cycle. This additional heat input to the steam cycle is accommodated by a 2.8 percent increase in main steam and feedwater flows. The higher main steam flow requires an increase in the size of the main turbine-generator from 128.0 to 135.3 MWe. Significant state point changes for the bottoming side (steam cycle) are outlined in Table 3.

Because of the lower operating temperatures of the topping side components, the high temperature components of the HR/SR are supplied with flue gas at substantially reduced temperatures. The completion of combustion in the afterburner section of the HR/SR generates a gas inlet temperature to the superheater of 2245°F with no flue gas recirculation flow. Since this temperature is well below the maximum limit of 2400°F for superheater gas temperature, flue gas recirculation is not required and the flue gas recirculation fans are eliminated. Significant state point changes for the topping side (MHD systems) are outlined in Table 2.

The use of a regenerative combustor in the MHD-ETF plant results in only minor changes to the reference (CDER) ETF plant layout. The ETF configuration and layout is simplified and greater ease of operation is possible because of the following changes:

1) Elimination of the ITOH and the high temperature oxidant lines from the HR/SR building.

2) Elimination of the flue gas recirculation fans which are no longer required.

3) The addition of a feedwater heater upstream of the deaerator in order to reduce the temperature difference across the deaerator and be more compatible with conventional practice.

These changes are not normally shown on plant layout drawings or are considered insignificant when considering revisions to plant layout drawings.

The changes to the ETF configuration that could require changes to the plant layout are outlined as follows:

1) The probable increase in envelope dimensions for a regenerative combustor.

2) The addition of a liquid to gas (oxidant) closed-loop heat exchanger for transferring the combustor second stage and nozzle heat loads to the oxidant.

3) A slightly larger surface area for MHD channel with the same active length.

4) A slightly modified diffuser to match the new channel operating conditions.

5) A slightly larger (5.7 percent) turbine-generator.

6) A smaller (7.8 percent) electrostatic precipitator.

7) The anticipated increase in HR/SR envelope dimensions.

The anticipated increase in HR/SR envelope dimensions is attributed to the substantial changes in heat transfer areas for the radiant boiler and the superheater. Based on preliminary calculations, the decrease in gas temperatures and the increase of 34 MW of heat transferred in the radiant boiler require a 48 percent increase in radiant boiler heat transfer area. Similarly, the increase of 3 MW in heat transferred by the superheater combined with the reduction in gas temperatures require a 30 percent increase in superheater heat transfer area.

It is recommended that further studies be conducted to evaluate the economic impact of all the component changes required for incorporation of regenerative combustor cooling in the ETF design. Comprehensive cost investigations will be required to establish meaningful cost estimates for a substantially revised HR/SR assembly and for a regenerative combustor specifically designed for the MHD-ETF plant.

There could be significant reductions in capital expenditures because of the reduced MHD generator output. A reduction in MHD generator output should produce a corresponding reduction in consolidation circuits and inverters.

TABLE 1

ETF SYSTEM POWER SUMMARY(1), (2)

	Reference ETF Plant (CDER)	ETF Plant With Regenerative Combustor Cooling
MHD Electrical Power: MWe		
MHD DC Power Output	87.1	76.1
Steam Cycle Electrical Power: MWe		
Electrical Power Output	128.0	135.3
Gross Plant Electrical Output(3): MWe	213.0	211.4
Auxiliary Power Requirements(3): MWe	10.8	12.5
Net Plant Electrical Output: MWe	202.2	198.9
Plant Efficiency: %	38.0	37.4
Plant Heat Rate: Btu/kW-hr	8979.7	9,128.1

Notes: (1) Performance of ETF plant with Regenerative Combustor Cooling is based on coal input parameters, oxygen flow rate, and oxygen content shown on System Heat and Mass Balance, Drawing No. 8270-1-540-314-001.

(2) Performance of ETF plant with Regenerative Combustor Cooling can be improved by optimizing input and performance parameters.

(3) Excluding compressor and BFP power.

TABLE 2

**MAJOR STATE POINT CHANGES
TOPPING SIDE (MHD GENERATOR)
WITH REGENERATIVE COMBUSTOR COOLING**

	Reference ETF Plant (CDER)	ETF Plant With Regenerative Combustor Cooling	Change Relative to Reference ETF Plant (+ Increase) (- Decrease)
MHD Power Train			
1. **Combustor**			
Oxidant Preheat Temperature, °F	1,100	778	-322°F
Discharge Temperature, °F	4,380	4,270	-110°F
Discharge Pressure, psia	66	56	-15.2%
2. Channel			
Power Output, MWe	87.1	76.1	-12.6%
Heat Loss, MWt	22.9	19.6	-14.4%
Oxidant Supply			
Oxidant Compressor Discharge Pressure, psia	72.8	61.1	-16.1%
Oxidant Compressor Discharge Temperature, °F	433	384	-49°F
Power Input for Oxidant Compressor, MWe	23.4	20.5	-12.4%
HR/SR			
1. Radiant Boiler			
Heat Load, MWt	141.0	175.1	+24.1%
Gas Temperature Change Across Boiler, Δt, °F	1,343	1,632	+289°F
Feedwater Inlet Temperature, °F	637	585	-52°F

TABLE 2 (Cont'd)

	Reference ETF Plant (CDER)	ETF Plant With Regenerative Combustor Cooling	Change Relative to Reference ETF Plant (+ Increase) (- Decrease)
2. **Afterburner**			
Flame Temperature, °F	2,400	2,245	-155°F
Flue Gas Recirculation Flow, lbm/hr	105,671	0	-100%
3. **Superheater**			
Heat Load, MWt	107.9	110.9	+2.8%
Gas Temperature Change Across Superheater, Wt, °F	807	953	+146°F
Gas Mass Flow, lbm/hr	1,357,352	1,251,682	-7.8%
4. **Reheater**			
Heat Load, MWt	55.2	56.8	+2.9%
Gas Temperature Change Across Reheater, Wt, °F	488	542	+54°F
Gass Mass Flow, lbm/hr	1,357,352	1,251,682	-7.8%
5. **High Temp. Economizer**			
Heat Load, MWt	28.6	26.3	-8.0%
Gas Mass Flow Rate, lbm/hr	1,357,352	1,251,682	-7.8%

TABLE 3

MAJOR STATE POINT CHANGES BOTTOMING SIDE (STEAM CYCLE) WITH REGENERATIVE COMBUSTOR COOLING

	Reference ETF Plant (CDER)	ETF Plant With Regenerative Combustor Cooling	Change Relative to Reference ETF Plant (+ Increase) (- Decrease)
Main & Reheat Steam System			
Steam Flow to High Pressure Turbine, $\frac{lbm}{hr}$	1,070,992	1,100,794	+ 2.8%
Steam Flow to Oxidant Compressor Drive Turbine, $\frac{lbm}{hr}$	190,220	166,027	-12.7%
Steam Flow to Reheat Turbine, $\frac{lbm}{hr}$	678,800	730,686	+ 7.6%
Turbine-Generator Output, MWe	128.0	135.3	+ 5.7%
Boiler Feedwater System			
Main Feedwater Flow, $\frac{lbm}{hr}$	1,070,992	1,100,794	+ 2.8%
Condensate System			
Deaerator Pressure, psia	15	19	+26.7%
Feedwater Δt Across Deaerator, ^{o}F	112	124	$+12^{o}F$
Extraction Steam Flow to Deaerator, $\frac{lbm}{hr}$	68,120	80,981	+18.9%

GAI Ref. No. 081-388-308
Engineering Study 308(1)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 308(1)

OPERATIONAL COSTS OF THE MHD-ETF FOR THE COMMERCIAL PHASE

PREPARED FOR

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY

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SEPTEMBER 1981

TITLE: Operational Costs of the ETF

SCOPE:

Operating and maintenance (O&M) costs of the ETF during its commercial phase of operation were calculated. These costs were derived from O&M costs for new, coal-fired conventional power plants and these in turn were adjusted in accordance with the anticipated influence of Magnetohydrodynamic (MHD) subsystems and interfaces. Major MHD equipment reviewed were: channel, combustor, and magnet. Seed and fuel costs were estimated separately.

FINDINGS:

Operating cost of the ETF, less fuel and seed, when in commercial operation, is calculated as 7.6 mills per Kilowatt hour $\left(\frac{m}{kWh}\right)$ in first quarter 1981 dollars. Fuel costs were 3.59 $\frac{m}{kWh}$. Seed costs, based on purchase of K_2CO_3 from a Vendor and recycle of recovered K_2SO_4 and resale of excess K_2SO_4 were 9.32 $\frac{m}{kWh}$.

RECOMMENDATIONS:

Fixed yearly operating costs and dollar costs to repair or replace a specific component can be estimated. Resultant unit costs, mills per kWh, can be reduced by increased production of energy and by increased time between failures of components. These goals are compatible; design and construction techniques should stress reliability and prolonged duration of operation.

PROCEDURE:

A review of conventional coal fired power plant O&M costs relative to plant sizes was made. Major MHD related equipment were evaluated individually. Yearly costs for Montana sub-bituminous coal were calculated based on delivery costs of $0.40 a million Btu*. Seed costs for new potassium carbonate, including shipping costs to site, were obtained and the credit for excess potassium sulfate mixture at the site deducted.

DISCUSSION:

Pertinent statistical data for determination of cost of power are not readily available for conventional power plants. Published surveys[1,2**] give scattered data and, generally, insufficient information to provide direct comparisons with projected power plants. Using the available data the correlations are presented in Table 1 which shows normalized capital plant costs and maintenance costs for different plant sizes and Figure 1 which shows the relationship of unit power O&M costs and plant costs as a function of plant size. The ratios used follow analytic expectancies since actual data do not support a well defined trend envelope. All costs have been normalized by assigning unity to the 400 MWe plant (dividing all values by the analogous value calculated for the 400 MWe plant). For coal fired conventional power plants the 400 MW capacity range is a transition for economy of scale; benefits diminish for higher ratings.

TABLE 1

NORMALIZED PLANT COST AND O&M COST AS A FUNCTION OF PLANT SIZE

Plant Size MW	Plant Capital Cost ($)	Plant Unit Cost ($/kW)	O&M ($/yr)	O&M Unit Cost m/kWh
50	0.233	1.86	0.25	2.0
100	0.365	1.46	0.425	1.7
200	0.65	1.3	0.7	1.4
400	1.0	1.0	1.0	1.0
800	1.7	0.85	1.4	0.7
1,000	2.0	0.8	1.75	0.7

Planned and scheduled O&M costs average about twice the costs of forced outage O&M costs. Planned O & M costs include wages of operating personnel whose number is estimated for the continuous operation plus a reserve to handle the peaks incurred during breakdowns or disruptive operating conditions. The trend for number of operating employees is increasing with

* Montana Power Co. averaged $0.30 a million Btu in 1978 (Steam Electric Plant Factors, 1979)

** Numbers refer to References

plants coming on line but the variation is large. For Class IX coal fired plants (500 to 999 MW) listed manpower[2] ranges from 61 to 385. For the 20 coal fired facilities submitting data, ranging in size from 300 MW to over 2,000 MW, the manpower extremes were 61 and 385; median was 178; mean was 196. For the commercial operation of the ETF an estimated 121 operating employees would be needed, apportioned as follows:

Supervision	22
Operators	30
Maintenance	35
Fuel, Ash & Seed Handling	8
Clerks, Laborers	14
Guards	12
Total	121

A manpower loading for the ETF concept as a test facility has been made by GE.[3] At full operation they show a complement of 238 personnel. About 60 of those would be included under administrative and general. The remainder, nominally 180, are within the range between minimum and maximum which could be utilized by a dual cycle plant. Wages of the 121 operating personnel, estimated in this report, are included, prorated, in the O&M costs shown for plant systems.

To obtain data for a specific Montana siting, operating statistics for Montana Power Company Plants were reviewed.[4] Plants included were Bird, primarily gas fired with a 69 MW rating, and Colstrip and Corette, primarily coal fired with ratings of 717 and 172 MW respectively. Total steam power production expenses were \$8.8 (10^6) in 1978 dollars, excluding fuel costs. For a 65 percent capacity factor, this is 1.6 $\frac{m}{kWh}$;

$$\frac{8.8\ (10^9)\ \text{mills}}{0.65\ (69+172+717)\ 10^3\ \text{KW} \times 8760\ \text{hr}} = 1.6\ \frac{m}{kWh}$$

Using Figure 1 the weighted average O&M factor for the three conventional plants would be 0.963. This compares to a factor of 1.4 for a conventional 200 MW plant. Using the ratio of 1.4 to 0.963 and inflating to first quarter 1981 dollars gives a value of 2.9 $\frac{m}{kWh}$ for an ETF sized plant based on past operating data.

For dual cycle MHD/steam power plants there are no statistical data. Economic studies are influenced by uncertainties in undemonstrated hardware. Commercial evaluations require judgment which may vary with different investigators. Equipment factors considered for this report are:

Channel

A channel is expected to be repaired and replaced 3.4 times per year at a cost of \$520(10^3) per replacement (nine replacements and a 50 percent salvage of parts). This includes the 191 man-hours for channel removal from and replacement to its operating position. (Refer to sub-task 306-2, Channel Replacement for details) Total O&M cost per year is \$1.8(10^6), equivalent to 1.5 $\frac{m}{kWh}$.

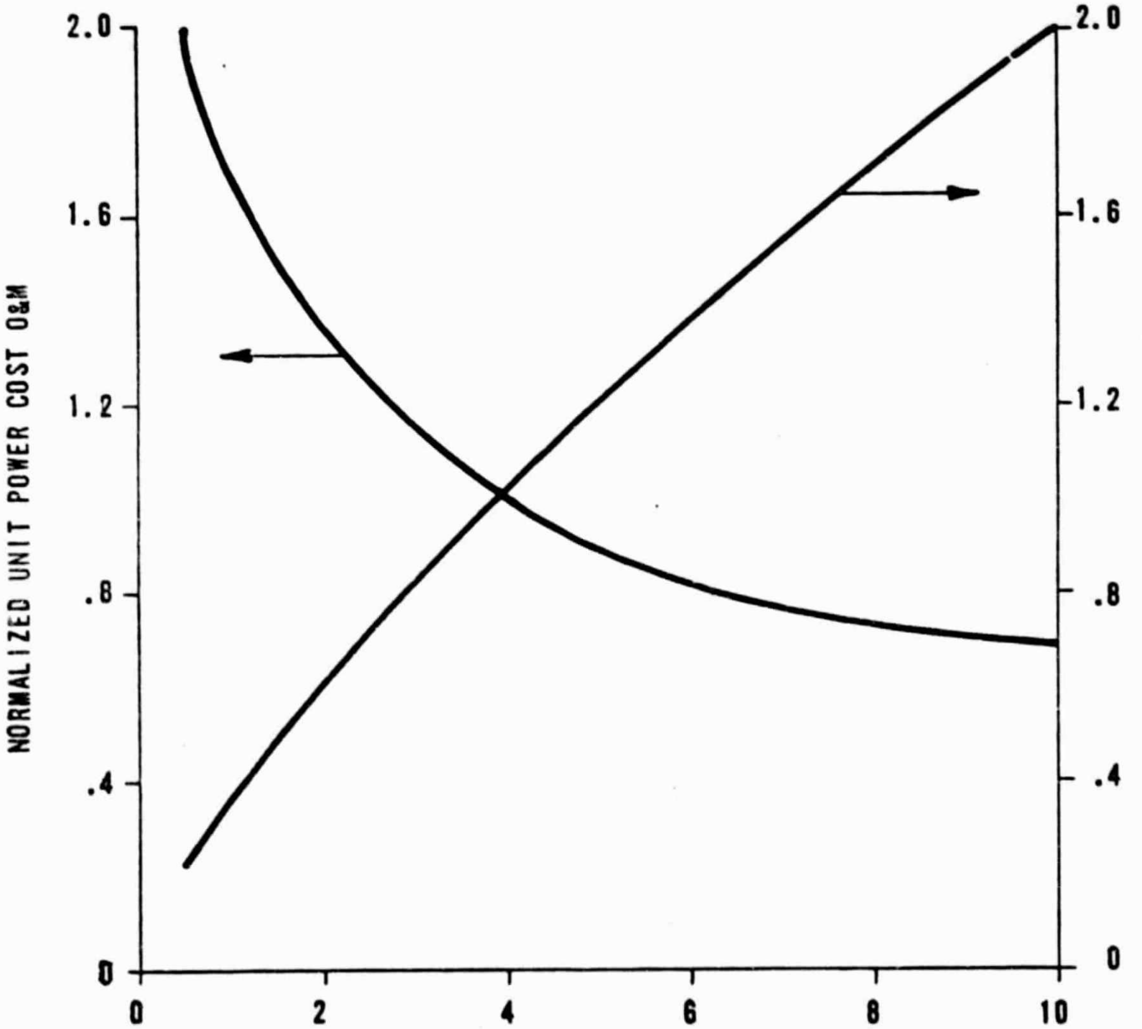

FIGURE 1
COMPARISON OF NORMALIZED O&M COSTS AND
PLANT COSTS AS A FUNCTION OF PLANT SIZE

Magnet

Design, construction and operating surveillance of the magnet will be in accordance with prescribed code requirements for commercial operation. Failure of the magnet under operating loads could cause considerable damage to adjacent areas of the plant. When constructed in compliance with established standards, warm-up and full inspection and replacement of modules is assumed every eight years (analogous to generator stator overhaul). Outage time for the ETF magnet presently defined would be 3 months and cost $8.0(10^6)$. An additional $600(10^3)$ per year would be expended on magnet support systems. Total O&M per year is $1.6(10^6)$ or 1.4 $\frac{m}{kWh}$.

Inversion - Consolidation

Large size Inverters used for dc transmission line application have demonstrated good reliability. Consolidation circuitry, because of the large quantity of smaller items of equipment (reliability is a function of size) will have more severe maintenance requirements. Inverter O&M is estimated at $240(10^3)$ per year, and consolidation circuitry at $480(10^3)$. Total yearly O&M costs of $720(10^3)$ is equivalent to 0.6 $\frac{m}{kWh}$.

Combustor

Combustor maintenance costs are considered analogous to boiler plant equipment costs and are taken as 4 percent of combustion system capital costs (See HR/SR below). O&M costs per year are $520(10^3)$ or 0.45 $\frac{m}{kWh}$.

Heat Recovery/Seed Recovery System (HR/SR)

Boiler plant O&M amounts to about 3.8 percent of boiler system capital costs. These costs include 60 to 70 percent of conventional plant maintenance costs. ETF modifications for wet bottom, reducing atmospheres and seed environment introduce additional maintenance requirements. These, however are offset by the absence of a scrubber. Yearly O&M costs are estimated at $3(10^6)$ or 2.6 $\frac{m}{kWh}$.

The specific systems reviewed represent about 50 percent of facility capital costs. Their combined O&M unit costs in mills per Kilowatt hour are:

Channel	1.5
Magnet	1.4
Inversion-Consolidation	0.6
Combustor	0.45
HR/SR	2.6
	6.55

The balance of plant systems include lower maintenance items and reflect 1/2 of the total plant cost. Using the value of 2.9 $\frac{m}{kWh}$ generated for an entire ETF sized plant as a base, the value was multiplied by 2/3 to pertain to low O&M items and by 1/2 since only 1/2 the plant is included. This gives an incremental O&M of about 1 $\frac{m}{kWh}$ and adds up to a total ETF O&M of 7.6 $\frac{m}{kWh}$.

Cost of fuel for the ETF is:

$$FC = F \times Q = \frac{\$0.40}{10^6\ \text{Btu}} \times 8{,}972\ \frac{\text{Btu}}{\text{kWh}} \times 10^3\ \frac{\text{m}}{\$} = 3.589\ \frac{\text{m}}{\text{kWh}}$$

where

F = unit fuel cost = \$0.40 per 10^6 Btu

Q = plant heat rate = 8,972 $\frac{\text{Btu}}{\text{kWh}}$

Cost of seed for the ETF is:

Cc = Cost of K_2CO_3 to site = \$546 per ton (includes \$21 per ton shipping charges at \$0.07 per ton mile)
Cs = Value of reclaimed "seed" on-site = \$50 per ton
P = Plant rating = 202350 kW
SC = Seed cost
Rc = Use rate of K_2CO_3 per full load hour = 7,992 lb
Rs = Reclaim rate of "seed" per full load hour = 11,797 lb

$$SC = \left[\frac{Cc \times Rc}{P} - \frac{Cs \times Rs}{P}\right] \times \frac{10^3\ \frac{\text{m}}{\$}}{2{,}000\ \frac{\text{lb}}{\text{Ton}}}$$

$$= \frac{\left[\frac{\$546}{\text{Ton}} \times 7{,}992\ \frac{\text{lb}}{\text{hr}} - \frac{\$50}{\text{Ton}} \times 11{,}797\ \frac{\text{lb}}{\text{hr}}\right] \times 10^3\ \frac{\text{m}}{\$}}{202{,}350\ \text{kW} \times 2{,}000\ \frac{\text{lb}}{\text{Ton}}}$$

$$= 9.32\ \frac{\text{m}}{\text{kWh}}$$

Note that use of K_2CO_3 as a seed removes sulfur upstream, eliminating need for a scrubber. In a conventional coal fired plant plant, the effects of capital costs of a scrubber and the operating costs of power and chemicals, plus maintenance of the scrubber and necessary sludge handling and storage, are comparable to the seed cost effects on total cost of power.

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2. Electrical World, November 15, 1979

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4. Statistics of Privately Owned Electric Utilities in the United States - 1978, U. S. Department of Energy, DOE/EIA - 0044(78)

GAI Ref. No. 091-430-308
Engineering Study No. 308(2)

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 308

PRE-OPERATIONAL TESTING OF MHD-ETF TOPPING CYCLE COMPONENTS

PREPARED FOR
MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY
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SEPTEMBER 1981

TITLE: Pre-Operational Testing of MHD ETF Topping Cycle Components

SCOPE:

The objectives of this special engineering study are to identify the pre-operational test requirements for the MHD-ETF topping cycle and to assess the capability of the plant to support on-site testing of MHD components which have been assembled at the site and previously not tested. Special test equipment necessary to conduct pre-operational tests of the MHD are also to be identified.

FINDINGS:

- Pre-operational testing of the MHD power train will likely not be possible until the topping cycle is ready for Integrated System (IS) tests.

- Full load testing of the MHD power train will be limited by startup and operation of the Air Separation Unit (ASU) and oxidant compressors. These subsystems in turn are limited by steam generation in the bottoming plant. Therefore, full load testing of the MHD power train cannot occur until initiation of Combined Plant Integrated System (CPIS) tests.

- To conduct integrated system tests of the topping cycle independent of the bottoming plant, an exhaust by-pass subsystem is required which will divert the diffuser exhaust gas to a quench duct. The system will include a scrubber and an Induced Draft (ID) fan. The existing stack will be utilized.

- The vitiation air heater which will be used for plant startup sequences will also be necessary for MHD IS and CPIS tests.

RECOMMENDATIONS:

To avoid an extended pre-operational test schedule and to minimize technical and start-up risks, it is recommended that MHD power train and the steam bottoming plant undergo parallel and basically independent pre-operational testing. To accomplish this independent pre-operational testing, Special Test Equipment (STE) to be required.

- Independent pre-operational testing of the MHD power train will require the installation of an exhaust by-pass system which is currently not included in the ETF design.

- Independent pre-operational testing of the bottoming plant will require an auxiliary burner system for the Heat Recovery/Seed Recovery (HRSR) system which is currently not included in the ETF design.

- An assessment of the cost and benefits of independent pre-operational testing of the MHD topping cycle and the steam bottoming cycle will require more detailed evaluation and study of the test program.

PROCEDURE:

The data for this engineering study was developed by integrating information obtained from:

- o Engineering design data being prepared by GAI for the MHD ETF Conceptual Design Engineering Report[1]
- o Previous GAI experience with conventional power plant pre-operational test/startup procedures and schedules.
- o Published data on the CDIF startup and acceptance plan[2,3]
- o Published data on the CDIF hardware checkout plan[4]
- o Engineering design data prepared by GAI for the MHD ETF Design Requirements Document[5]

DISCUSSION:

A. Introduction

During the construction and startup phase of the ETF, a series of pre-operational tests will be conducted to ensure that all components and systems will perform according to engineering specifications and can be operated safely. The pre-operational tests to be conducted will be similar in scope and intent as those performed for a conventional coal fired power plant. However, for the ETF, it will be necessary to define additional specific pre-operational test requirements for MHD topping cycle components.

Many pre-operational tests to be performed for topping cycle components will be done in parallel with or subsequent to other subsystem or auxiliary tests. Therefore, it is necessary to consider pre-operational testing of the entire plant on an integrated basis in order to obtain an overall perspective of how the MHD components will fit into the total test schedule. An examination of the pre-operational test requirements for the entire plant is beyond the scope of work for the present study. However, a generic construction/start-up schedule for the ETF has been assumed and is used for descriptive purposes.

A simplified generic construction/start-up schedule assumed for the ETF is given in Figure 1. Pre-operational testing of the MHD topping cycle is shown to occur in parallel with pre-operational testing of the bottoming plant. In each of these parallel schedules there are four types of operational tests to be conducted: Construction Component Checkout (CCC) Tests, System Operation (SO) Tests, Integrated System (IS) Tests and Combined Plant Integrated System (CPIS) Tests. Definitions and terminology used in this report are included in Appendix A attached to this report.

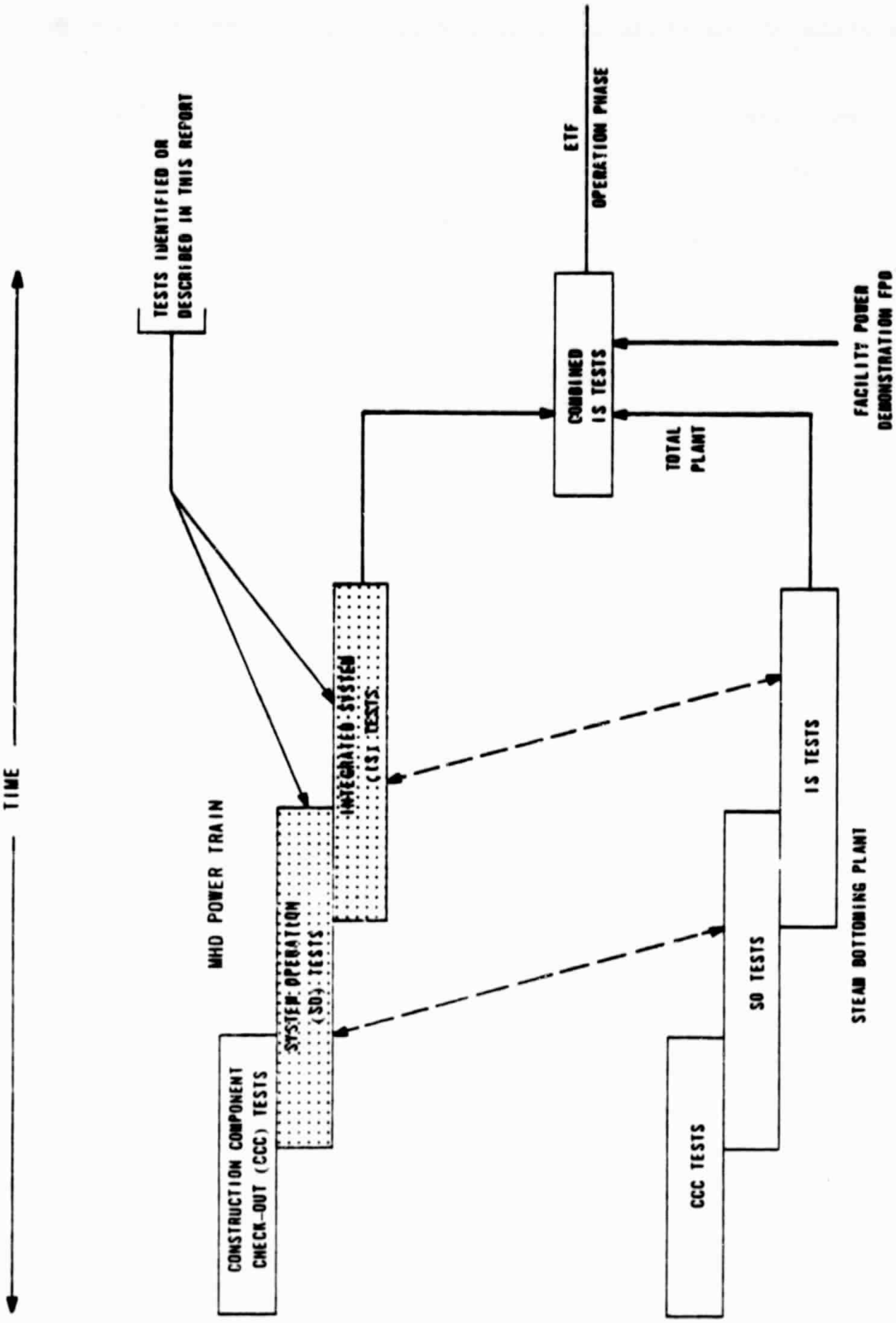

FIGURE 1
GENERIC PRE-OPERATIONAL TEST SCHEDULE FOR ETF
DURING CONSTRUCTION/START-UP PHASE

Briefly, the CCC tests are carried out by the construction contractor at the end of the construction phase of the plant and prior to turn-over of the facility to the plant operator. In general, these tests are not extensive, their primary purpose is to assure that the installation and connection to components are in conformance with the drawings and technical specifications. During the CCC tests, major components are put into a state of readiness to allow for performance verification under subsequent SO tests.

The SO tests are performed by the plant operator on individual systems to verify that the system is ready to be put into service and that the system operates in accordance with its technical specification. These tests pertain mainly to facility systems rather than power train systems. SO tests for MHD support auxiliaries will be conducted; however, it is not anticipated that component testing of MHD systems will be conducted during SO test sequences.

The IS tests are performed by the operator on groups of interdependent facility and power train systems to ensure they can perform certain functions. These tests determine performance envelopes for the interrelated systems. During IS testing, cold, warm and hot runs of the MHD flow train will be made independently of bottoming cycle operation via a by-pass duct located at the MHD transition section.

The CPIS tests will be performed by the operator subsequent to completion of both the topping cycle and the bottoming cycle IS tests. During the CPIS tests, the plant will be run in a combined topping cycle/bottoming cycle mode, with cold, warm and hot startup procedures being utilized as appropriate. Upon completion of the CPIS tests, the plant will have a Facility Power Demonstration (FPD) which is an integral part of the plant commissioning.

A review of pre-operation test requirements for MHD topping cycle components indicates that MHD systems including the combustor, nozzle channel, diffuser, magnet and inverter will not undergo shakedown and testing until the plant is ready for Integrated System (IS) tests. The present study therefore focuses on the IS tests for the MHD power train. However, the auxiliary systems SO tests required prior to conducting the IS tests are also briefly highlighted. Some of the SO and IS tests necessary for the MHD topping cycle are also be required for the bottoming plant. Therefore, interaction of the test requirements for both the topping cycle and bottoming cycle is conceptually depicted by the dashed lines in Figure 1. The tests which have been identified and which will be described in this report are shown by the shaded areas in Figure 1.

B. MHD Power Train Auxiliary System Operation (SO) Tests

SO tests of the MHD components will not be conducted; however, SO tests of auxiliaries and major subsystems will be necessary prior to initiating MHD IS tests.

Subsequent to turn-over of the facility by the constructor to the operator, facility SO tests should be run by the operator to assure the performance of components satisfies engineering specifications. The test procedures will be the responsibility of the operator. The intent of these tests will be to verify performance of facility equipment, e.g: pump flow, pressure, R.P.M., electric motor amps, volts, R.P.M., compressor flow, pressure temperature, I&C calibrations, etc. The sequence of these tests will start with the basic facility stand-alone systems such as facility water service, electric service, etc., and proceed to more complex systems which are dependent on the operation of one or more other systems (e.g., auxiliary steam is dependent on plant water service, fuel oil distribution and plant electric service). The following systems will undergo SO testing, and the sequencing of these tests are depicted in Figure 2.

- Plant Waste Water Service
- Plant Electric Service
- Plant Air Service
- Fuel Oil Distribution
- Instrumentation and Controls for Central Control Room
- Data Acquisition System
- Magnet DC Supply
- Pumps (Electric Drive)
- Inverter Interconnect Cabling
- Slag Collection and Removal
- Cooling Water System
- Auxiliary Steam System
- Air Separation Unit
- Oxygen Compressor
- Oxidant Compressor
- Feed Water Pump
- Nitrogen Storage
- Oxygen Storage
- Coal Material Handling
- Coal Crusher
- Coal Predrying
- Coal Pulverizing & Drying System
- Coal Injection System
- Seed Material Handling
- Seed Injection System
- Exhaust By-Pass System

C. ETF Integrated System Tests

After completion of SO tests, and the facility support systems have been determined to be operating within specifications, Integrated System (IS) Tests of the MHD flow train can be initiated. These tests encompass the combined operation of interrelated facility systems, MHD power train support equipment, MHD power train components, and MHD power train/facility operation. Test specifications and test procedures for this series of tests will be the responsibility of the ETF operator. Independent sets of IS tests will be run for both the MHD power train and the bottoming plant.

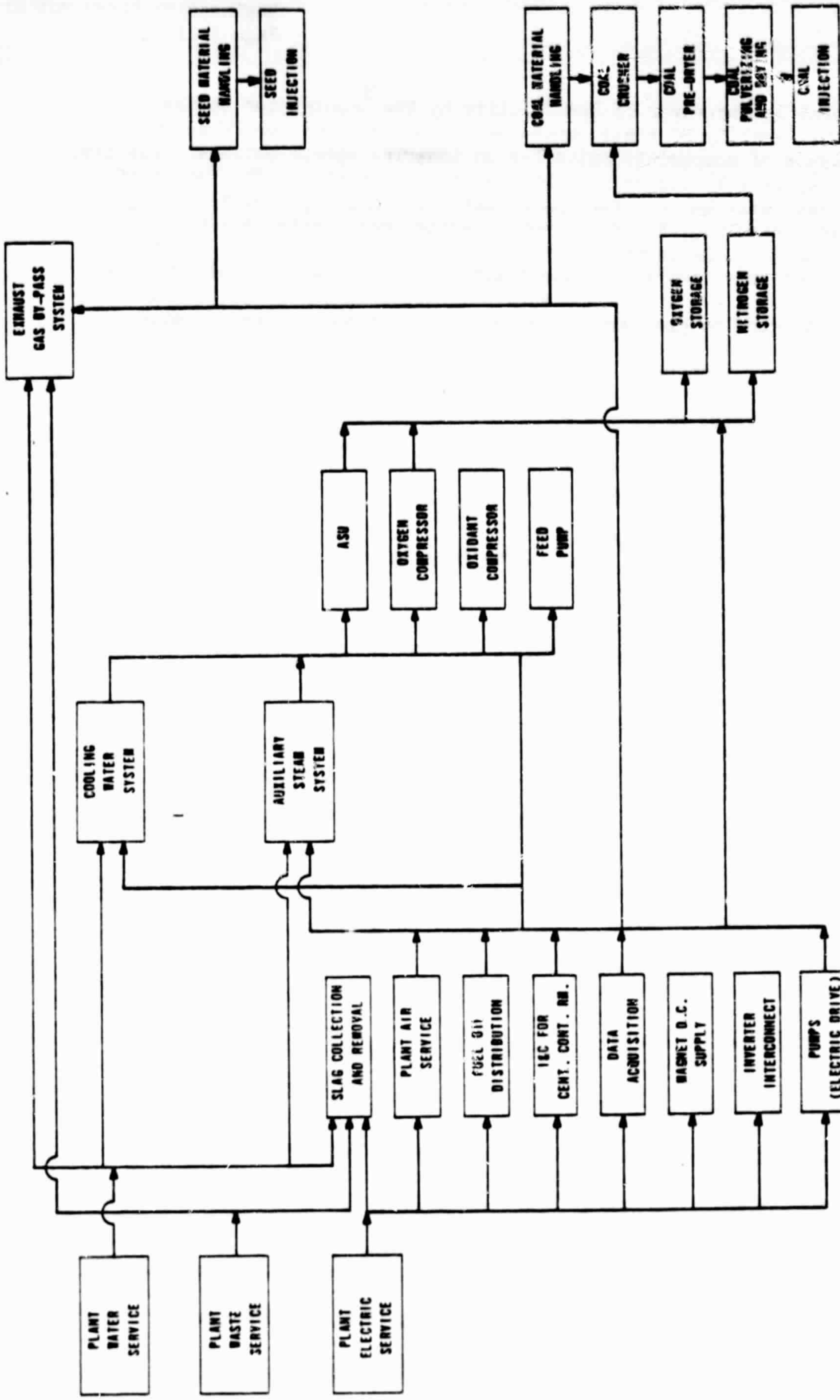

FIGURE 2
ETF PRE-OPERATIONAL
SYSTEM OPERATING TEST SEQUENCE

Summary descriptions of the Integrated System (IS) test for the MHD flow train are given below and their sequence is depicted in Figure 3.

Data Acquisition System Test: This test will verify the operational integrity of the entire Data Acquisition System from the calibration of the test data source, through the various electronic devices, to computer display and storage of data. This test will include checking all sensing devices, alarm systems, displays, digital output and computer functions for accurate, acceptable operation. Subsequent to this the DAS will be utilized in all IST tests.

Magnet System Test: The magnet power supply will initially be checked out. Transformer, rectifier and associated equipment will be checked to ensure proper operation, calibration, phasing, system protection, polarity, and voltage and current levels.

Subsequent to this the magnet cryogenic, vacuum, and I&C subsystems will be individually tested for proper operations. Upon successful completion of these checkouts, total magnet operation will be tested by initiating cool down to the proper level followed by a step-wise sequence of charging and recharging the magnet until full magnet field strength is obtained.

Feed Water/Auxiliary Steam/Cooling Water Test: The channel/diffuser cooling/feed water systems will be tested using hot water from the auxiliary steam plant. System flow, pressure ranges and water purity will be checked against system specifications.

ASU/Oxidant System Test: Air for cold, warm and hot flow testing of the MHD power train will be provided by the motor driven oxidant compressor which is rated at 50 percent of full load capacity. Oxygen for the MHD IS tests will be provided by trucked-in supplies of liquid O_2. Performance capabilities of the oxidant compressor and ASU delivery system over various ranges of pressures and flows will be determined. Blend air will be vented to the atmosphere as necessary.

Coal Handling, Processing, and Delivery System Test: The test will verify the required rates of transferring and handling coal from railroad unloader to the coarse crusher hopper, processing it to prepared coal storage, and finally injecting coal from prepared coal storage to the combustor injection piping interface. Key parameters to be checked and monitored are inerting nitrogen flow and pressures, oxygen content, coal particle size, coal flow rate measurement accuracy, and coal injection density. Associated alarms, switches, indicators, relief valves, interlocks, and controls will be checked.

Integrated Combustor Feed Test: All feed systems to the combustor will be tested simultaneously. Flow rates and pressures will be validated. Operation of interdependent controls, interlocks, and instrumentation will be verified for startup and shutdown.

Exhaust Bypass and Integrated Combustor Feed Test: This test will be a continuation of the previous test with the addition of the operation of

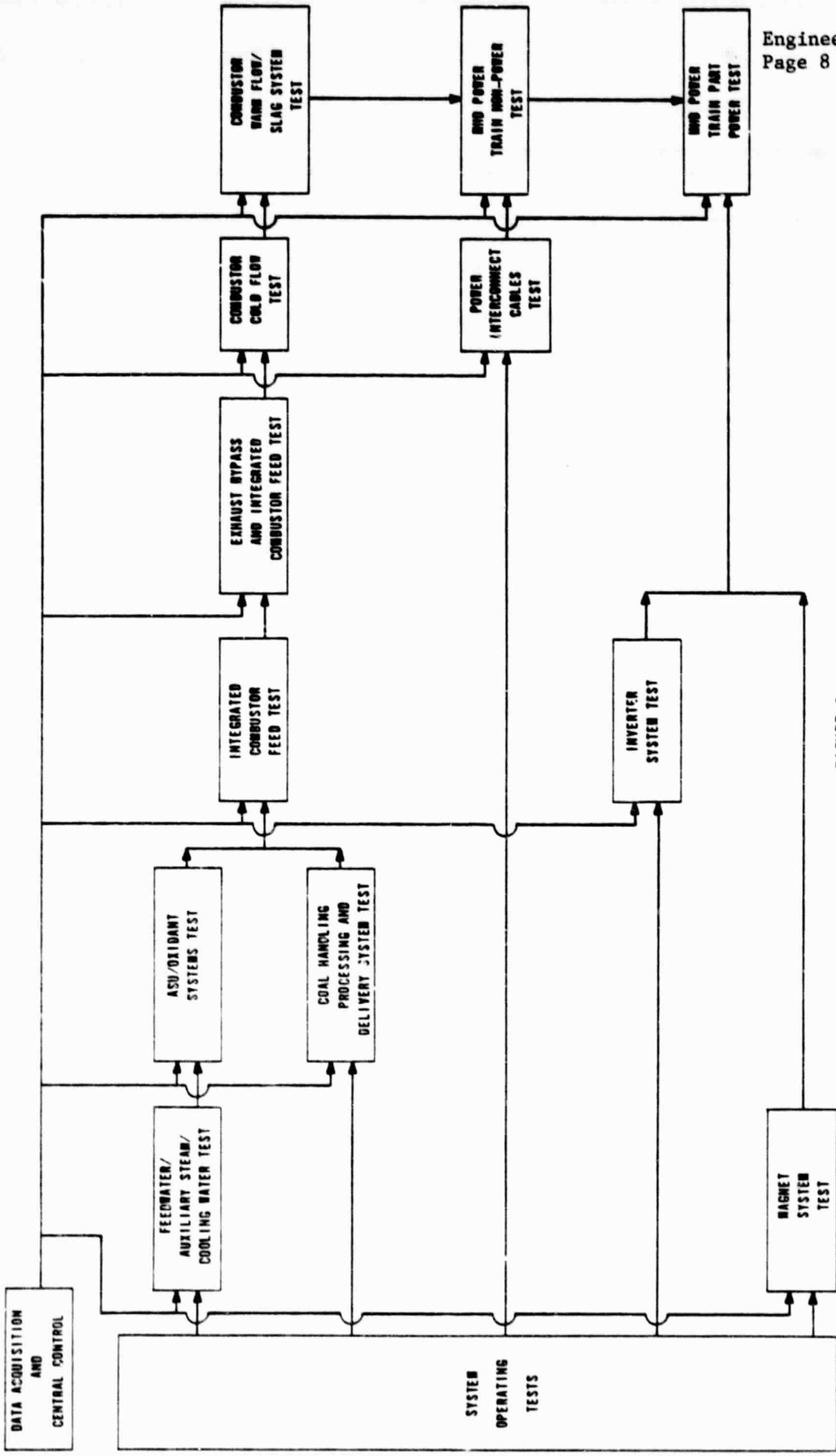

FIGURE 3
ETF PRE-OPERATIONAL
INTEGRATED SYSTEM TEST SEQUENCE

the exhaust quench, scrubber and ID fan. The capability of the exhaust bypass to quench and scrub particulate matter from the gas stream will be verified. All mechanical systems will be checked for correct operating sequence during startup and shutdown simulations.

Combustor Cold Flow Tests: With the coal fired combustor in place, various flows of unheated oxidant up to maximum flow will be run through the combustor and the exhaust bypass subsystem. Leak integrity will be checked as well as pressures, flows, and I&C operation.

Combustor Warm Flow/Slag System Test: This test will demonstrate startup and shutdown procedures for the coal combustor. Startup will be demonstrated using the vitiated air heater. Since this is the initial combustor startup, oxygen will not be used. This test will familiarize the operators with startup and shutdown procedures. The test should exercise the majority of combustor feed systems and demonstrate their physical integrity as well as their control functions. Proper operation of the slag removal system will be demonstrated.

Power Interconnect Cable Test: This test will validate all electrical power cable hook-ups to the channel and all instrumentation and control lead connections.

MHD Power Train-Non Power Test: This test will initially check out the use of oxygen in the coal combustor. A range of stoichiometries will be examined. Controllability of varying airflow and oxygen flow will be determined. Optimum combustor performance will be determined as a function of temperature and pressure measurement. Channel plasma conductivity will be mapped by imposing a current across the channel electrodes. Heat flux, slagging characteristics and cooling system functioning will be determined.

Inverter System Test: This test will validate inverter performance, integrity and controllability. Steady state and transient operations will be covered.

MHD Power Train Power Test: This test will validate the integrated operation of the facility support systems and the MHD power train. This test will demonstrate the physical integrity of the system and will verify the operation of the interdependent control systems. It will also provide the ability to make any necessary calibrations and adjustments to the control system and its feedback loops. This test will include a parameter study of pressures, temperatures, heat losses and transient response as a function of flow rates.

D. Special Test Equipment Requirements for MHD Power Train Testing in an ETF

The ETF Design Requirements Document (DRD)[5] does not provide any requirements for testing the MHD power train independent of the steam bottoming plant. To accomplish this testing, several major equipment subsystems have been identified which are required to be altered or added to the ETF design. This equipment will be called Special Test Equipment

(STE), since their use or total capacity will not be required for normal ETF operation. The major STE required for MHD power train testing separate from the steam bottoming plant are as follows:

- o An exhaust by-pass and quench subsystem to divert the diffuser exhaust gas to a quench duct. The system will include a scrubber and an ID fan. The existing stack will be utilized.
- o A feed water by-pass to divert feed water from the diffuser/ transition sections directly to the condenser with appropriate throttling.
- o A vitiated air heater to be employed only for MHD power train start-up and testing.

As the ETF design matures and planning for testing becomes more definitive, the requirements for other STE will most likely become evident. These requirements should be included in future revisions of the DRD and need to be incorporated into the design process.

REFERENCES:

1. MHD ETF Conceptual Design Engineering Report, prepared by Gilbert/ Commonwealth for NASA LeRC under contract DEN 3-224, dated March 1981.

2. "CDIF Startup and Acceptance Test Plan", prepared by the Montana Energy and MHD Research and Development Institute for DOE under contract AC07-78-ID-01745, Report No. 2DOE-MHD-D56.

3. "CDIF Facility Startup and Acceptance Test Plan", prepared by the Montana Energy and MHD Research and Development Institute, dated 27 Dec 1976.

4. "Test Train Components & Interface Hardware Checkout Plan, CDIF/MHD Test Train 1A," prepared by the Westinghouse Electric Corporation for DOE under contract EF-77-C-01-2612, Report TME-2918, Nov 30, 1978 Revision C.

5. MHD Engineering Test Facility Design Requirements Document (DRD), prepared by Gilbert/Commonwealth for DOE and NASL LeRC, Report DOE/NASA/ 2674-80, March 1981.

APPENDIX A
DEFINITIONS AND TERMINOLOGY

Combined Plant Integrated System (CPIS) Tests: Upon completion of independent IS tests for the MHD power train and the bottoming plant, CPIS tests will be performed by the operator to determine the performance envelopes for the combined plants. Cold, warm and hot flow test sequences of the plant will be run and startup/shutdown procedures will be evaluated prior to the Facility Power Demonstration.

Construction Component Checkout (CCC): These are tests that are performed by the Construction Contractor prior to turn-over of the facility to the operator. The purpose of these tests is to assure that the installation and connections to components are in conformance with the drawings and technical specifications, and to assure readiness of the equipment for performance verification.

Construction Contractor: A construction engineering firm which has contracted with the government to construct the ETF.

Facility Power Demonstration (FPD): The FPD is an integral part of the plant commissioning, and consists of verifying that the plant can be started up and will operate according to the rated design specifications.

Integrated System (IS) Tests: These are tests performed by the operator on groups of facility and power train sytems that are interdependant to verify they can perform certain functions. These tests determine performance envelopes for the interrelated systems.

Plant Operator: A firm "usually a Utility" which has contracted with the government to operate the ETF.

Preoperational Test: Component, subsystem, system and integrated system tests to confirm that specified performance is met and to define operating envelopes. These tests are conducted prior to operation.

Special Test Equipment (STE): Equipment, apparatus, hardware, instrumentation, etc., needed during testing of either facility elements or power train components. This equipment may be needed to form an interface between power train components, power train/facility components or facility components.

System Operating (SO) Tests: These are tests performed by the operator on individual systems to verify that the system is ready to be put into service and that the system operates in accordance with its technical specifications. These tests pertain mainly to facility systems rather than power train systems.

Technical Specification: A set of standards which defines the characteristics and performance required of facility components to establish their acceptability for inclusion into a facility system.

APPENDIX A (Cont'd)

Test Procedure: A document which defines the specific objectives of a test, and details the steps required to accomplish the full intent of each phase.

Test Specification: A set of standards which defines the performance required of facility and power train systems to certify their capabilities relative to power train support requirements, and which serves as a basis for establishing test procedures.

5.2.3 Supplemental Data

Supplemental cost and schedule data was provided by the developers of the high technology equipment for the ETF conceptual design. The data was used to develop the ETF cost estimate found in Section 3.3, and is included as the following attachments to this section of the CDER:

System	Cost/Schedule Data
Magnet	Cost Estimate, 3/9/81 (2 sheets)
	Manufacturing and Installation Schedule, 3/2/81 (2 sheets)
Oxidant Supply	Lotepro Cost Estimate, 3/9/81 (4 sheets)
	Lotepro Project Schedule, 3/12-13/81 (6 sheets)
MHD Power Train	Cost Estimate, 3/6/81 (6 sheets)
	Manufacturing and Construction Schedule (1 sheet)
HR/SR	Cost Estimate, 3/6/81 (10 sheets)
	Recommended Schedule (1 sheet)

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Rev. 3/13/8

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SUMMARY COST ESTIMATE[1,2]

ETF MAGNET SYSTEM

CONCEPTUAL DESIGN

ACCT. NO.	ACCOUNT DESCRIPTION	QUANTITY	MATERIAL COST MJR COMP	MATERIAL COST UOA	INST. COST	INDIR COST	CONTIN	TOTAL COST
317.3	MAGNET SYSTEM	1	33,446	80	6,500	650	11,766	52,442
	ENGINEERING SERVICES (FIELD)	-	-	-	3,254	-	651	3,905
	OTHER COSTS	-	-	-	1,099	-	220	1,319
	TOTAL ESTIMATED COSTS	-	33,446	80	10,853	650	12,637	57,666

[1] This cost estimate does not include foundations. Estimated costs of foundations for magnet system are to be supplied by Gilbert Associates, Inc.

[2] Costs are K$, mid 1981

DATE: 3/9/81
Rev. 3/13/81

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COST ESTIMATE BREAKDOWN[1,7]

ETF MAGNET SYSTEM - CONCEPTUAL DESIGN

ACCT. NO.	ACCOUNT DESCRIPTION	QUAN.	DESIGN & ANAL.	MAT'L & MFG.	SHOP ENG'G.	PACK & SHIP	MATERIAL COST[2] MJR COMP	MATERIAL COST[2] BOA	INST COST	INDIR COST	ENG'G SERV. 8	OTHER COST	CONTIN	TOTAL COST
317.3.1	Magnet assembly													
317.3.1.1	On-site tools						2,070		400					
.2	Roll-aside track						621		150					
.3	Wind. contain vessels[3]						15,870		1,800					
.4	Main structure						5,244		800					
.5	Cold mass supp. struts						621		150					
.6	Therm. rad. shield						1,518		900					
.7	Vacuum vessel						3,036		1,200					
.8	Warm bore liner						621		80					
	Total magnet assembly	1	5,363	21,450	2,145	643	29,601	-	5,600	560	(2,861)	(966)	10,728	46,489
317.3.2	Support subsystems													
317.3.2.1	Hydro. actuator sys.						128		30					
.2	Cryogenic supp. system						1,536		250					
.3	Power supply & dis. sys.						1,152		150					
.4	Main vacuum pump sys.						256		70					
.5	Utility boom, contr., misc.						640		100					
	Total support system	1 set	725	2,900	-	87	3,712	-	600	60	(350)	(118)	874	5,246
317.3.3	Magnet shakedown test	-	150[4]	60	20	2	232[4]	80[5]	300[6]	30	(51)	(17)	193	835
	Total						33,446	80	6,500	650			11,766	52,442
	Engineering Services										3,254		651	3,905
	Other cost											1,099	220	1,319
317.3	TOTAL													57,666

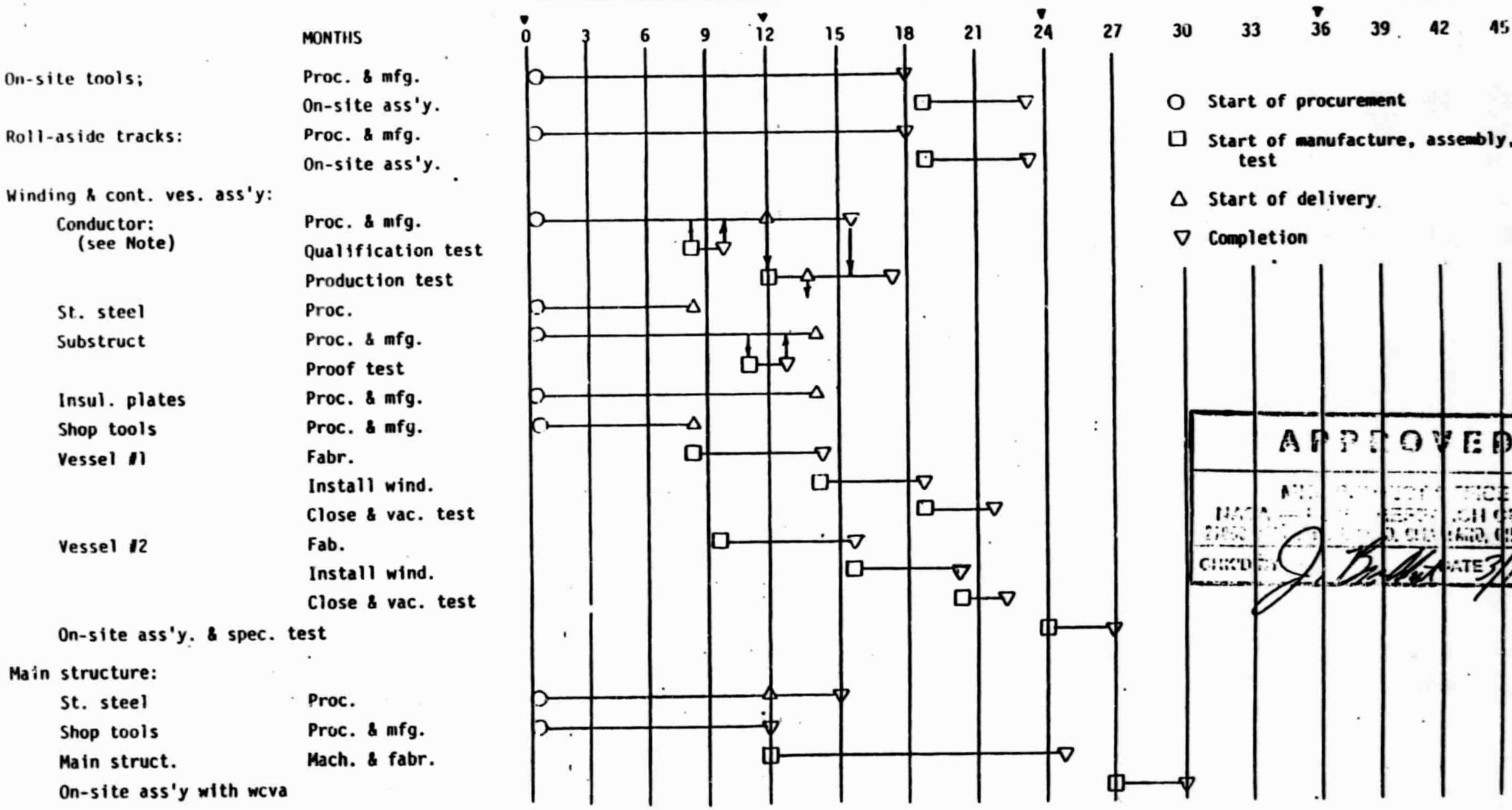
1 This estimate does not include foundations.
2 Material cost is FOB site.
3 This item includes conductor, coil winding (in shop) and shop assembly.
4 Includes 100 K$ eng'g. test supervision and analysis.
5 Includes liquid nitrogen and liquid helium.
6 On-site technician labor cost.
7 Costs are K$; mid 1981
8 Field engineering

SCHEDULE - MANUFACTURING AND INSTALLATION

MHD - ETF 200 MWe POWER PLANT MAGNET SYSTEM

SHEET 1

3/2/81



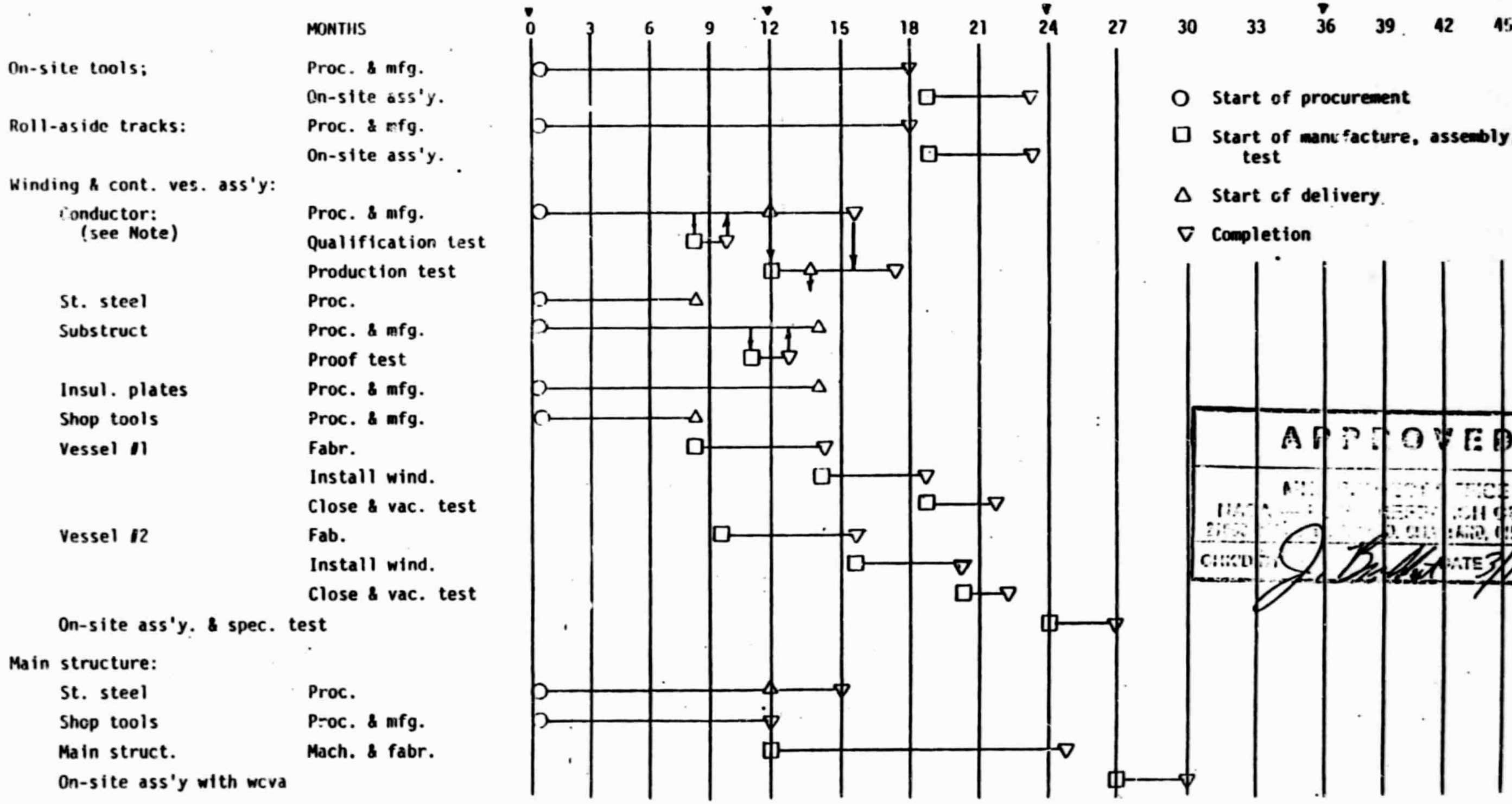
NOTE: Schedule for conductor assumes that sample lot of full-scale conductor has been made and qualified prior to start of procurement of production quantity.

SHEET 1

3/2/81

SCHEDULE - MANUFACTURING AND INSTALLATION

MHD - ETF 200 MWe POWER PLANT MAGNET SYSTEM



NOTE: Schedule for conductor assumes that sample lot of full-scale conductor has been made and qualified prior to start of procurement of production quantity.

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BASE CASE (Rev. 1)

Lotepro Cost Estimate
for ETF Oxidant Supply System
Excluding concrete foundations and for Middletown, U.S.A. Site

(in thousands of dollars)

Account No.	Account Description	Qty	Mjr. Comp.	*BOA	Inst Cost	Indir Cost	Contin	Total Cost
317.5	Oxidant Supply System							
317.51	Oxidant Comp. System							
317.511	Oxidant Comps	3	3280	60	1040	540	760	5680
317.512	Motor Drive	1	550	32	210	110	70	972
317.513	Turbine Drive	2	2000	30	540	270	70	2910
317.514	Steam Condenser	2	380	--	110	50	30	570
317.52	Mixing Chamber	1	40	--	20	10	--	70
317.7	Air Separation Unit							
317.71	Cold Boxes							
317.711	Column Box	1	2060	150	620	310	180	3320
317.712	Heat Exchange Box	2	2380	170	710	360	210	3830
317.713	Adsorber Box	1	1410	100	400	200	125	2235
317.714	Valve Box	1	580	80	200	100	55	1015
317.72	ASU Air Comp. System							
317.721	ASU Air Comp.	1	2760	50	810	400	240	4260
317.722	Driver	1	1290	20	360	180	100	1950
317.723	Aftercooler	1	150	40	40	20	10	260
317.724	Steam Condenser	1	270	20	80	40	20	430
317.73	Expanders	2	460	50	140	70	40	760
317.74	Storage System							
317.741	Lox Tank	1	170	20	40	20	10	260
317.742	Lox Vaporizer	1	40	40	20	10	--	110
317.743	Lin Tank	1	30	20	20	10	--	80
317.744	Lin Vaporizer	1	10	10	5	5	--	30
	SUBTOTALS		17,860	892	5,365	2,705	1,920	28,672
	Engineering Services				1,650			1,650
	Supervision				810			810
	Other Costs							
	TOTAL ESTIMATED COSTS		17,860	892	7,825	2,705	1,920	31,132

Rev. 1

*Included in BOA are all interconnecting piping, associated valves, and [illegible]entation.

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VARIATION #1 (Rev. 1)

Lotepro Cost Estimate
for ETF Oxidant Supply System
Excluding CONCRETE Foundations and for Middletown, U.S.A. Site

(in thousands of dollars)
#1 Variation: Excluding drivers for the 3 oxidant and 1 ASU Compressor

Account No.	Account Description	Qty	Mjr. Comp.	BOA*	Inst Cost	Indir Cost	Contin	Total Cost
317.5	Oxidant Supply System							
317.51	Oxidant Comp. System							
317.511	Oxidant Comps	3	3280	60	1040	540	760	5680
317.512	Motor Drive							
317.513	Turbine Drive							
317.514	Steam Condenser							
317.52	Mixing Chamber	1	40	--	20	10	--	70
317.7	Air Separation Unit							
317.71	Cold Boxes							
317.711	Column Box	1	2060	150	620	310	180	3320
317.712	Heat Exchange Box	2	2380	170	710	360	210	3830
317.713	Adsorber Box	1	1410	100	400	200	125	2235
317.714	Valve Box	1	580	80	200	100	55	1015
317.72	ASU Air Comp. System							
317.721	ASU Air Comp.	1	2760	50	810	400	240	4260
317.722	Driver							
317.723	Aftercooler	1	150	40	40	20	10	260
317.724	Steam Condenser							
317.73	Expander	2	460	50	140	70	40	760
317.74	Storage System							
317.741	Lox Tank	1	170	20	40	20	10	260
317.742	Lox Vaporizer	1	40	40	20	10	--	110
317.743	Lin Tank	1	30	20	20	10	--	80
317.744	Lin Vaporizer	1	10	10	5	5	--	30
	SUBTOTALS		13,370	790	4,065	2,055	1,630	21,910
	Engineering Services				1,650			1,650
	Supervision				810			810
	Other Costs							
	TOTAL ESTIMATED COSTS		13,370	790	6,525	2,055	1,630	24,370

*Included in BOA are all interconnecting piping, associated valves, and instrumentation.

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APP

VARIATION #2 (Rev. 1)

Lotepro Cost Estimate
for ETF Oxidant Supply System
Excluding concrete foundations and for Middletown, U.S.A. Site

3/14/81

(in thousands of dollars)

#2 Variation: With single oxidant compressor (steam drive) replacing the 3 oxidant compressors of Base Case

Account No.	Account Description	Qty	Mjr. Comp.	BOA*	Inst Cost	Indir Cost	Contin	Total Cost
317.5	Oxidant Supply System							
317.51	Oxidant Comp. System							
317.511	Oxidant Comps	1	1780	60	540	320	400	3100
317.512	Motor Drive							
317.513	Turbine Drive	1	1200	30	310	150	40	1730
317.514	Steam Condenser	2	380	--	110	50	30	570
317.52	Mixing Chamber	1	40	--	20	10	--	70
317.7	Air Separation Unit							
317,71	Cold Boxes							
317.711	Column Box	1	2060	150	620	310	180	3320
317.712	Heat Exchange Box	2	2380	170	360	210	210	3830
317.713	Adsorber Box	1	1410	100	400	200	125	2235
317.714	Valve Box	1	580	80	200	100	55	1015
317.72	ASU Air Comp. System							
317.721	ASU Air Comp.	1	2760	50	810	400	240	4260
317.722	Driver	1	1290	20	360	180	100	1950
317.723	Aftercooler	1	150	40	40	20	10	260
317.724	Steam Condenser	1	270	20	80	40	20	430
317.73	Expander	2	460	50	140	70	40	760
317.74	Storage System							
317.741	Lox Tank	1	170	20	40	20	10	260
317.742	Lox Vaporizer	1	40	40	20	10	--	110
317.743	Lin Tank	1	30	20	20	10	--	80
317.744	Lin Vaporizer	1	10	10	5	5	--	30
	SUBTOTALS		15,010	860	4,425	2,255	1,460	24,010
	Engineering Services				1,650			1,650
	Supervision				810			810
	Other Costs							
	TOTAL ESTIMATED COSTS		15,010	860	6,885	2,255	1,460	26,470

*Included in BOA are all interconnecting piping, associated valves, and instrumentation.

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LOTEPRO CORPORATION

ALTERNATIVE COSTS: MONTANA SITE

					Totals		
		Mjr Comp	BOA*	Inst Cost	Indir Cost	Contin	Total Cost
1.	Base Case	17,860	892	7,310	2,445	1,910	30,417
2.	Variation #1	13,370	790	6,162	1,858	1,620	23,800
3.	Variation #2	15,010	860	6,460	2,038	1,450	25,818

* Included in BOA are all interconnecting piping, associated valves and instrumentation.

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CHK'D BY J. Burkhart DATE 3/14/81

SCHEDULE: ETF OXIDANT SUPPLY SYSTEM

Lotepro CORPORATION

LEGEND:
S Schedule date
A Actual date
1 Spec. issued f. quotation
2 Quotation received
3 Purchase order issued
4 Equipment drawing 1st issue
5 Drawing approval
6 All mat'l at fabr.
7 Fabr. released
8 Fabr. completed
9 Testing completed
UD Unchecked dwg.
CD Checked dwg.
DA Dwg. approval
CR Constr. released
SH Shipment
R Rec'd at site

LOTEPRO
PROJECT SCHEDULE

ENG. TEST FACILITY

Job No.: SE 5026
Rev. :
Date : 3/12/81
By : EJC
Page : 1of 6

Item No.	Description	Sub No.	Vendor	P.O. No.		1st YEAR												2nd YEAR												3rd YEAR												4th YEAR
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1.	PROCESS DESIGN				S																																					
					A																																					
2.	PROCESS INSTRUMENTATION DIAGRAMS				S																																					
					A																																					
3.	SECURE PROCESS EQUIP. DATA		from VENDORS		S																																					
					A																																					
4.	PLOT PLAN & ELEVATION		DRAWINGS		S																																					
					A																																					
5.	STORAGE TANKS				S													1	2	3		5											9	R								
					A																																					
6.	STEAM CONDENSERS				S				1		2	3		5										9	R																	
					A																																					
7.	MIXING CHAMBER				S				1		2	3		5										9	R																	
					A																																					
8.	ASU COMPRESSOR				S	1	2		3				5															R														
					A																																					
9.	OXIDANT COMPRESSORS				S	1	2		3				5															R														
					A																																					
10.	STEAM TURBINE DRIVES				S	1		2		3			5															R														
					A																																					
11.	LARGE MOTOR DRIVE				S		1	2		3			5															R														
					A																																					
12.	COLD BOX VESSELS				S	3		4				5										R																				
					A																																					

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LEGEND:

S	Schedule date	5	Drawing approval	CD	Checked dwg.
A	Actual date	6	All mat'l at fabr.	DA	Dwg. approval
1	Spec. issued f. quotation	7	Fabr. released	CR	Constr. released
2	Quotation received	8	Fabr. completed	SH	Shipment
3	Purchase order issued	9	Testing completed	R	Rec'd at site
4	Equipment drawing 1st issue	UD	Unchecked dwg.		

SCHEDULE: ETF OXIDANT SUPPLY SYSTEM

LOTEPRO

PROJECT SCHEDULE

ENG. TEST FACILITY

Lotepro Corporation
Job No.: SE 5026
Rev. :
Date : 3/12/81
By : FJC
Page : 2of 6

Item No.	Description	Sub No.	Vendor	P.O. No.		1st YEAR												2nd YEAR												3rd YEAR												4th YEAR
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1	REVERSING EXCHANGERS				S		1	2		3				5												R																
					A																																					
2	COLD BOX PIPING				S													1			2	5	3					R														
					A																																					
3	COLD BOX STRUCT. STEEL				S										4		1		2	5	3						R															
					A																																					
4	EXPANSION TURBINE				S																4	1		2		5		3		R												
					A																																					
5	FIELD FAB YARD PIPING				S																4	1			2			5		3		R										
					A																																					
6	SHOP FAB COMPR. BLDG PIPING				S																4		1		2		5		3	R												
					A																																					
7	FIELD FAB COMPR. BLDG. PIPING				S																4		1	2		5		3		R												
					A																																					
8	PIPE VALVES FITTINGS				S													1		2		3								R												
					A																																					
9	FOUND. DESIGN EXCL. BLDG.				S								5	1	2																											
					A																																					
10	STRUCTURAL DESIGN				S									5		1	2		3					R																		
					A																																					
11	COMPRESSOR BUILDING				S		1		2	3				R																												
					A																																					
12	FOUND. DESIGN BUILDING	by	GAI		S					5	1	2	3																													
					A																																					

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LEGEND:

S	Schedule date	5	Drawing approval	CD	Checked dwg.
A	Actual date	6	All mat'l at fabr.	DA	Dwg. approval
1	Spec. issued f. quotation	7	Fabr. released	CR	Constr. released
2	Quotation received	8	Fabr. completed	SH	Shipment
3	Purchase order issued	9	Testing completed	R	Rec'd at Marsh.Yard
4	Equipment drawing 1st issue	UD	Unchecked dwg.		

SCHEDULE: ETF OXIDANT SUPPLY SYSTEM
LOTEPRO

PROJECT SCHEDULE

ENG. TEST FACILITY

Lotepro Corporation
Job No.: SE 5026
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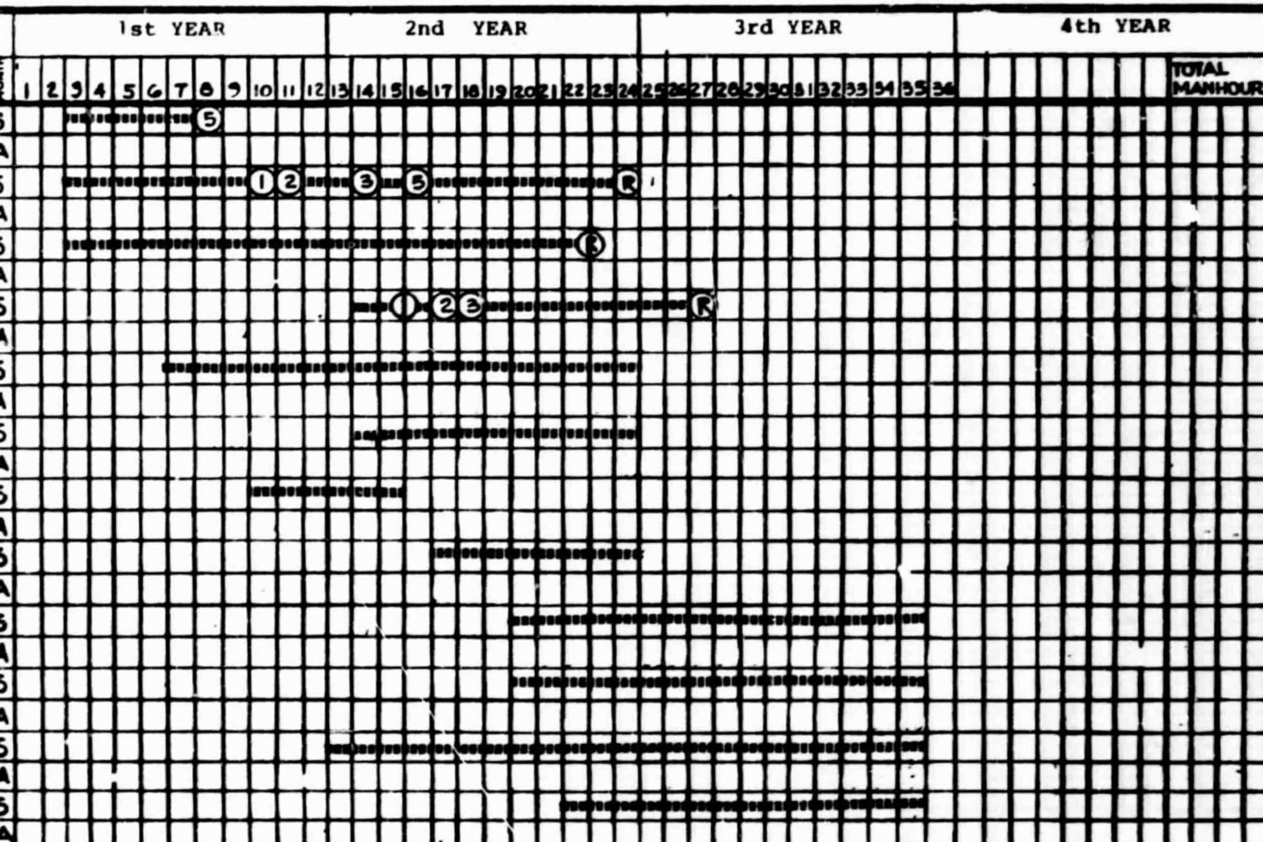
Item No.	Description	Sub No.	Vendor	P.O. No.	Month
	ELECTRICAL ONE LINE				S
					A
	ELECTRICAL EQUIPMENT				S
					A
	INSTRUMENT-ATION				S
					A
	INSULATION SHOP/FIELD				S
					A
	CIVIL AND SITE PREP.				S
					A
	FOUNDATION	by GAI			S
					A
	BUILDING				S
					A
	STRUCTURAL				S
					A
	EQUIPMENT ERECTION				S
					A
	PIPING ERECTION				S
					A
	ELECTRICAL				S
					A
	INSTRUMENT-ATION				S
					A



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SCHEDULE ETF OXIDANT SUPPLY SYSTEM

LEGEND:

S	Schedule date	5	Drawing approval	CD	Checked dwg.
A	Actual date	6	All mat'l at fabr.	DA	Dwg. approval
1	Spec. issued f. quotation	7	Fabr. released	CR	Constr. released
2	Quotation received	8	Fabr. completed	SH	Shipment
3	Purchase order issued	9	Testing completed	R	Rec'd at site
4	Equipment drawing 1st issue	UD	Unchecked dwg.		

LOTEPRO

PROJECT SCHEDULE

ENG. TEST FACILITY

Lotepro Corporation
Job No.: SE 5026
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Item No.	Description	Sub No.	Vendor	P.O. No.		1st YEAR (1–12)	2nd YEAR (13–24)	3rd YEAR (25–36)	4th YEAR
	INSULATION (Field)				S				
					A				
	EQUIPMENT CHECK-OUT and RUN. IN				S				
					A				
	DERIMING (MOISTURE ELIMINATION)				S				
					A				
					S				
					A				

LEGEND:

- L LOTEPRO/LINDE EMPLOYEE
- V VENDOR REPRESENTATIVE
- S SUBCONTRACTOR STAFF EMPLOYEE
- H LOCAL HIRE AT SITE
- INTERMITTENT INSPECTION AS REQUIRED ▪▪▪▪▪▪▪▪▪▪▪▪
- APPROXIMATE DURATION ONLY ▬ ▪ ▬ ▪ ▬

SCHEDULE: ETF OXIDANT SUPPLY SYSTEM

PROJECT SCHEDULE

ENG. TEST FACILITY

KEY FIELD SUPERVISION

Lotepro Corporation
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By : EFH
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Item No.		CODE	1st YEAR (months 1–12)	2nd YEAR (months 13–24)	3rd YEAR (months 25–36)	4th YEAR
	SITE MANAGEMENT					
	CONSTRUCTION MGR.	L				
	ASST. CONST. MGR.	L				
	SENIOR ENGINEER	L				
	ADMINISTRATIVE ASST.	L				
	PLANNING ENGINEER	H				
	PROJECT SECRETARY	H				
	QUALITY ASSURANCE SPECIALISTS					
	MECHANICAL - ROTARY	L				
	CIVIL	L				
	WELDING - PIPING	L				
	ELECTRICAL - ELECTRONIC	L				
	INSTRUMENTATION	L				
	CONTRACTOR SUPERVISION					
	CIVIL SUPERINTENDENT	S				
	MILLWRIGHT SUPERINTENDENT	S				
	PIPING SUPERINTENDENT	S				
	ELECTRICAL SUPERINTENDENT	S				
	INSTR. CONTROL SUPERINTENDENT	S				
	COMPRESSOR BLDG. REP.	V				
	ASU COMPRESSOR ERECTOR	V				
	OXIDANT COMPRESSOR ERECTOR	V				

SCHEDULE: ETF OXIDANT SUPPLY SYSTEM

PROJECT SCHEDULE

ENG. TEST FACILITY
KEY FIELD SUPERVISION

Lotepro Corporation
Job No.: SE 5026
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Item No.		CODE
	CONT: CONTRACTOR SUPERVISION	
	STEAM TURBINE ERECTOR	V
	LARGE MOTOR ERECTOR	V
	CRYOGENIC TANK ERECTOR	V
	INSULATING SUPERINTENDENT	S
	PAINTING SUPERINTENDENT	S
	PLANT START-UP ENGINEERS	
	SENIOR ENGINEER	L
	1st ASST. ENGINEER	L
	2nd ASST. ENGINEER	L
	3rd ASST. ENGINEER	L

1st YEAR: 1 2 3 4 5 6 7 8 9 10 11 12 — 2nd YEAR: 13 14 15 16 17 18 19 20 21 22 23 24 — 3rd YEAR: 25 26 27 28 29 30 31 32 33 34 35 36 — 4th YEAR

SDD-502 - MHD POWER TRAIN COST ESTIMATE[e] DATED MARCH 6, 1981

ACCOUNT NO.	ACCOUNT DESCRIPTION	UNIT	MATERIAL COST MJR COMP	MATERIAL COST BOA[c]	INST COST	INDIR COST	CONTIN.	TOTAL COST (THOUSAND)
317.1[a]	COMBUSTION EQUIPMENT	1	7309	5578	2880	1445	4386	21598
317.11	COAL DRYING	1	--	5578	1481	742	1562	9363
317.12	COAL INJECTION	1	4506	--	1198	601	1893	8198
317.13	COMBUSTOR	1	1903	--	45	22	592	2562
317.14	SLAG. COLLECT. EQPT.	1	900	--	156	80	339	1475
317.2[b]	MHD GENERATOR SYSTEM	1	8064	--	313	158	2562	11097
317.21	NOZZLE	1	253	--	7	4	79	343
317.22	CHANNEL	1	6550	--	163	81	2040	8834
317.23	DIFF. AND TRANSIT SECTION	1	1261	--	143	73	443	1920
317.4	ELECTRICAL CONSOLIDATION AND INVERSION	1	9510	--	2955	1478	4187	18130
317.41	INVERTERS	1	7279	--	2373	1187	3254	14093
317.42	CONSOLIDATION CIRCUITRY	1	2231	--	582	291	933	4037
317.6[c]	SEED SYSTEM	1	8297	--	2937	1471	3817	16552
317.61	SEED REGEN.	1	8034	--	2769	1387	3662	15852
317.62	SEED INJECTION	1	263	--	168	84	155	670
317	ENGINEERING SERVICES (FIELD)	1						2600

NOTES: (a) NOTE 16 - ETF CODE OF ACCOUNTS REV. JANUARY 5, 1981

(b) NOTE 17 - ETF CODE OF ACCOUNTS REV. JANUARY 5, 1981

(c) NOTE 21 - ETF CODE OF ACCOUNTS REV. JANUARY 5, 1981

(d) DOES NOT INCLUDE FOUNDATIONS, UNLESS INDICATED. TO BE PROVIDED BY GAI

(e) ALL COSTS (K$) CORRECTED TO MARCH 19, 1981, BASED ON ESCALATION OF 7% FOR 1977-1979 AND 12% FOR 1980-1981

COST BACK-UP

FOR

SDD-502 MHD POWER TRAIN COST ESTIMATE

A. Ground Rules

The cost estimate was prepared using the following ground rules:

1. The cost estimate is based on mid 1981 dollars.

2. Costs are shown in thousands of dollars.

3. The DOE Code of Accounts was used for all cost estimates. Costs are shown for accounts 317.1, 317.2, 317.4 and 317.6 at the account and subaccount level. An estimated total cost is shown for engineering services (field) for these accounts and is identified separately as account #317.

4. Cost estimate is based on a common (Middletown, USA) site.

Cost elements identified with each account and subaccount are identified as:

"Major Components" are those items which are engineered, designed, fabricated, shipped, and in some cases erected, by one supplier.

"Balance of Plant" items are normally designed, engineered and purchased by the engineer. All material costs include charges for delivery to the site.

The "Installation" portion of the direct cost includes wage costs for all manual labor, foremanship, and all wage related benefits and costs mandated by labor agreement. Payroll taxes, payroll premium costs and workmen's compensation insurance costs are built into the wage rate of direct labor costs. Also included is special construction equipment associated with certain civil work items to which the costs can be charged directly, and also contractor fees. Auxiliary labor for unloading, storing, sorting materials and equipment, general and final cleanup, and other miscellaneous activities directly associated with the installation of the work area are also charged to the direct account.

"Indirect Costs" for construction are those cost items which include facilities, equipment and services that are required to directly support the construction operations, but which cannot be conveniently charged by the constructor or general contractor directly to a single estimating account. For conceptual estimates, indirect construction costs are expressed as a percentage of the direct cost. Field offices and temporary facilities, transportation, safety equipment, construction tools and equipment, expendable supplies, nonmanual labor, construction services and testing contracts, and insurance and bonds are all examples of indirect costs.

"Contingency" represents the total contingency that has been applied to each line item. As Owner committed monies for purchased material and negotiated contracts proceeds towards 100% of total project cost, necessary contingency factors may be reduced in a manner to reflect lessened possibilities of unforeseeable circumstances occurring before project completion. As project engineering nears completion, estimating may deal with more precise information and can more accurately predict material quantities and respective project costs. Items incorporated into contingency management considerations include:

Design (but not major scope) changes

Market conditions

Labor productivity

State of project definition

Unreliable and noncurrent estimating data

Unpredictable field conditions

Instabilities of material and labor markets

Uncertainties in project timing

Errors and omissions

Weather

Short term strikes, walkouts, and other labor disputes

Other unforeseeable occurences and conditions which would delay or otherwise increase material and/or installation costs.

The contingency factors used in this report reflect the above items as well as varying degrees of development and uncertainty for the MHD components. In the case of Balance of Plant (BOP) structures, improvements and well defined mechanical systems, a 10% factor is used. For the higher technology components, a factor of 20% is used. High technology items are identified as:

Account	
317.14	Combustor
317.21	Nozzle
317.22	Channel
317.23	Diffuser and Transition
317.31-35	Magnet Subsystem
317.42	Electric Consolidation Circ.
317.61	Seed Regeneration Process

B. Basis

Two sources of cost data were used in the preparation of the cost equations. These are identified as:

1. Cost Base #1 AVCO-ETF Mid 1977 $ — AVCO ETF Conceptual Design; DOE/FE/2614-3, 1979

2. Cost Base #2 AVCO-CSPEC Mid 1978 $ — Conceptual Design Study of Potential Early Commercial MHD Power Plant; DOE/NASA/0051-2, NASA CR-165235, 1981

C. Method

1. Subaccount costs in cost base #1 (AVCO-ETF) and cost base #2 (AVCO-CSPEC) were adjusted to mid 1981 dollars using the following escalation factors:

(a) 7% increase for periods of 1977-1978 and 1978-1979

(b) 12% for periods of 1979-1980 and 1980-1981.

2. Subaccounts in cost base #1 were scaled up and the subaccounts in cost base #2 were scaled down to the current ETF size, using the appropriate parameters and cost equations shown in Appendix A.

Costs were computed for subaccounts 317.11, 317.12, 317.13, 317.14, 317.21, 317.22, 317.23, 317.61 and 317.62 in cost base #1 and cost base #2, using equations based on the ratio of thermal input power and the ratio of channel internal surface area. The costs for subaccounts 317.41 and 317.42 in cost base #1 and cost base #2 were computed using equations based on the ratio of MHD output electric power and the ratio of channel internal surface areas.

Two equations were used for each subaccount for checking and comparison purposes.

3. A scaled cost for each subaccount was selected for cost base #1 and for cost base #2. The costs of high technology components were increased by a factor of 1.4 (subaccounts 317.13, 317.21, 317.22, 317.23, 317.42 and 317.61).

4. Each subaccount cost computed from cost base #1 was averaged with the corresponding subaccount cost computed from cost base #2, providing the cost for the ETF cost estimate.

5. Cost elements (major components, BOP, installation, etc.) for each subaccount line item were computed from the total cost of each subaccount, using the corresponding percentage identified in cost base #2 (AVCO-CSPEC).

APPENDIX A

I. Cost Equations

A. Scaled Cost, Basis Ratio of Thermal Power

1.
$$\begin{pmatrix}\text{Base Cost \#1}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Input, MW}_t}{\text{AVCO-ETF Input MW}_t}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

2.
$$\begin{pmatrix}\text{Base Cost \#2}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Input, MW}_t}{\text{AVCO-CSPEC Input MW}_t}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

B. Scaled Cost, Basis Ratio of Channel Internal Surface Area

1.
$$\begin{pmatrix}\text{Base Cost \#1}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Area, Ft}^2}{\text{AVCO-ETF Area, Ft}^2}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

2.
$$\begin{pmatrix}\text{Base Cost \#2}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Area, Ft}^2}{\text{AVCO-CSPEC Area, Ft}^2}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

C. Scaled Cost Basis Ratio of MHD Electric Power Output

1.
$$\begin{pmatrix}\text{Base Cost \#1}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Output, MW}_e}{\text{AVCO-ETF Output, MW}_e}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

2.
$$\begin{pmatrix}\text{Base Cost \#2}\\ \text{Mid 1981 \$}\end{pmatrix} \times \left(\frac{\text{Current ETF Output, MW}_e}{\text{AVCO-ETF Output, MW}_e}\right)^{\text{scaling function}} = \text{scaled subaccount cost}$$

D. Subaccount Cost for Current ETF

$$\frac{\begin{pmatrix}\text{Subaccount}\\ \text{Cost Using}\\ \text{AVCO-ETF}\\ \text{Cost Base \#1}\end{pmatrix} + \begin{pmatrix}\text{Subaccount}\\ \text{Cost Using}\\ \text{AVCO-CSPEC}\\ \text{Cost Base \#2}\end{pmatrix}}{2} = \text{Subaccount Cost}$$

II. Parameters Used in Cost Equations

A. Thermal (Coal) Input

1. Cost Base #1 (AVCO-ETF) - 291 MW_t
2. Current ETF - 543 MW_t
3. Cost Base #2 (AVCO-CSPEC) - 2100 MW_t

B. Channel Internal Surface Areas

1. Cost Base #1 (AVCO-ETF) - 321 Ft^2
2. Current ETF - 522 Ft^2
3. Cost Base #2 (AVCO-CSPEC) - 1579 Ft^2

C. Electric Power Output

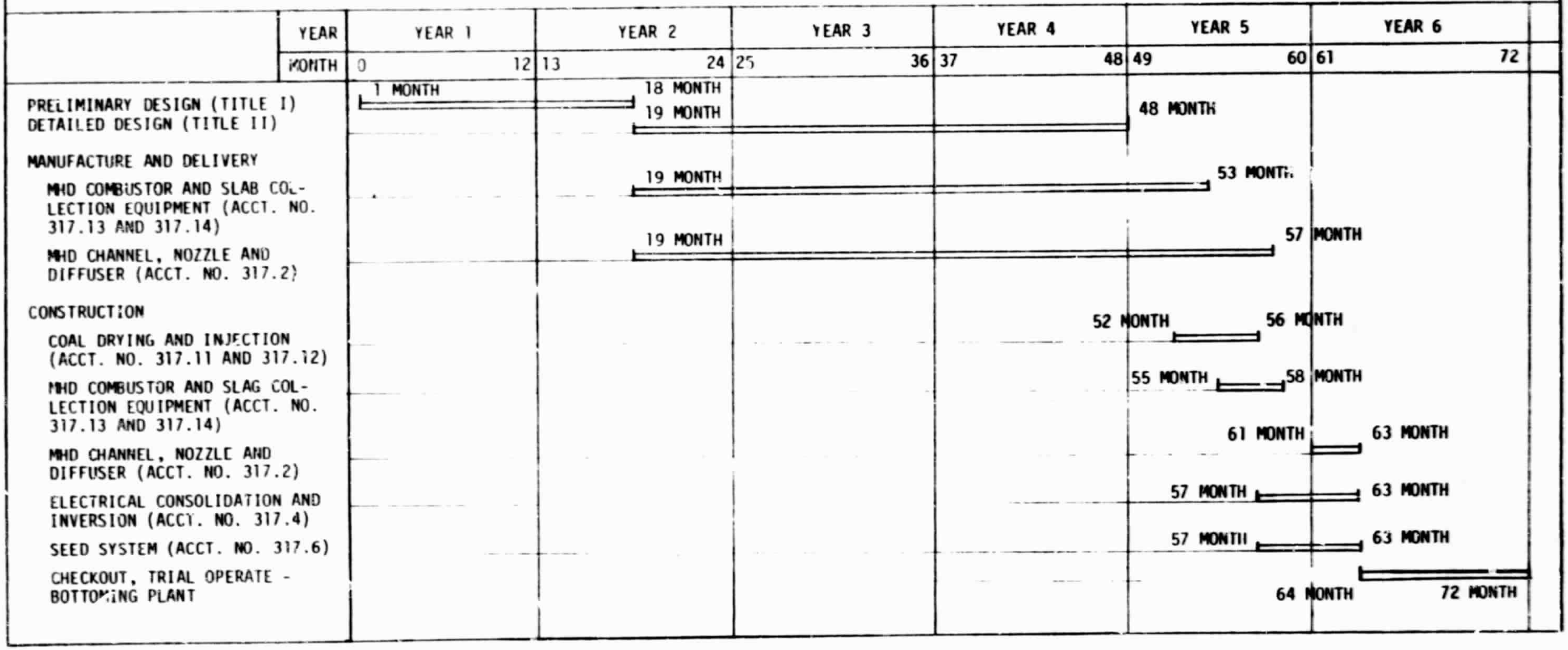
1. Cost Base #1 (AVCO-ETF) - 50.1 MW_e
2. Current ETF - 90 MW_e
3. Cost Base #2 (AVCO-CSPEC) - 525 MW_e

*D. Exponential Scaling Functions

1. Account #317.1, Combustion Equipment - 0.67
2. Account #317.2, MHD Generator System - 0.7
3. Account #317.4, Electric Consolidation and Inversion - 0.9
4. Account #317.6, Seed System - 0.67

*Provided by DOE

SDD-502 - MHD ETF POWER TRAIN SCHEDULE[(a)]



(a) BASIS OF SCHEDULE, "ENGINEERING TEST FACILITY CONCEPTUAL DESIGN" REPORT, FE-2614-2 DATED JUNE 1978.

March 6, 1981

ETF Conceptual Design-200MWe

COST ESTIMATE[1][2]

SDD-504 MHD ETF HR/SR

Account Number	Description	Characteristics	Major Material	*Balance of Account	Installation	*Indirects	Contingency	*Total Cost
312.4	HR/SR Steam Generator	1,070,992 #/hr steam (378MW)	$13,984,118		$ 9,145,545		$11,564,831	
312.5	Particulate Control	703,386 CFM @ 480°F 3.9 to 7.6g/SCF	6,680,374		226,639		690,701	

*This material is not included in the estimate and shall be provided by the A/E-GAI.

Note 1. All costs corrected to March 1981 based on 12% per year escalation, i.e., these costs are 6% higher than the values shown on attached worksheets.

2. Cost Estimate Breakdown is shown in ANL Cost Breakdown.

U.S. DEPARTMENT OF ENERGY
ARGONNE NATIONAL LABORATORY
9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439 TELEPHONE 312/972-

ETF Conceptual Design 200MWe
ANL-Recommended Cost Data

Cost Breakdown for HR/SR Boiler(1)

Account No. 312.4 - Boiler ("Steam Generator")

Category	Description	Cost(2)
Unit of Measure:	1,070,992 lb/hr superheated steam 378 MW thermal	
Material:	Material and Equipment supplied by Vendor a) Boiler - including oxidant heaters, structural steel, ductwork, and all engineering	$11,481,960
	b) Accessory Equipment supplied by Vendor including sootblowers, fans motors, controls, steam coil air heater	$ 1,710,604
	Total material	$13,192,564
Balance of Account:	this includes all items supplied in the field, i.e., Foundation, HR/SR Building, inlet and outlet flue gas ductwork, building electrical and wiring to boiler equipment electric service boxes. To be supplied by GAI	

(1)HR/SR boiler includes - Radiant Boiler Sections, Superheaters, Reheaters, Intermediate Temperature Oxidant Heaters, High Temperature Economizer, Steam Drum, and Recirculation Pumps, Downcomers, and Headers.

(2)Cost shown - based on September 1980 dollars - add 6% for March 1981 costs.

THE UNIVERSITY OF CHICAGO ARGONNE UNIVERSITIES ASSOCIATION

ETF Conceptual Design 200MWe

Cost Breakdown for HR/SR Boiler (continued)

Account No. 312.4 - Boiler ("Steam Generator")

Category	Description	Cost
Installation Costs:	This includes costs for erection of the boiler and associated structures, accessory equipment, ducting and air heater (BRIL is included in this price)(3)	
	a) Erection	$ 8,201,400
	b) Shipping	207,769
	c) Service (Field Engineer & Start Up Operating Crew)	218,704
	Total Installation	$ 8,627,873
Indirect Costs:	To be supplied by GAI	
Contingencies:	Allow 50% contingency for B&W supplied information due to fact that B&W estimate is 40% of CE 2X Base Case Cost Estimate	
	a) Materials - $13,192,564 X 50% =	$ 6,596,282
	b) Installation - $8,627,873 X 50% =	4,313,936
	Total Contingency	$10,910,218
Total cost Vendor (B&W) supplied items for HR/SR		
	a) Materials - $13,192,564 + $6,596,282 =	$19,788,846
	b) Installation - $8,627,873 + $4,313,936 =	12,941,809
		$32,730,655

(3) BRIL=Brickwork, Refractory, Insulation, & Lining

ETF Conceptual Design 200MWe

Cost Breakdown for Particulate Control (ESP)

Account No. 312.5 - Particulate Control

Category	Description		Cost[4]
Unit of Measure:	1,357,352 lb/hr Flue Gas @ 480°F =703,386 - CFM - @ 3.9 grains/SCF_{ANL} or 7.6 grains/SCF_{GAI}		
Material:	ESP as delivered to site		\$ 6,302,240
Balance of Account:	This includes all items supplied in the field-i.e., Foundation, DuctWork, Electrical Service Supply to ESP boxes		
	To be supplied by GAI		
Installation Costs:	This includes erection costs, shipping and checkout.		
	a) Erection -	\$168,810	
	b) Shipping -	22,500	
	c) Service -	22,500	
		\$213,810	\$ 213,810
Indirect Costs:	To be supplied by GAI		
Contingencies:	Allow 10%		
	Materials -	\$630,224	
	Installation -	21,381	
		\$651,605	\$ 651,605

Total Cost - B&W Supplied ESP

Materials - \$6,302,240 + \$630,224 =	\$6,932,464
Installation - \$213,810 + \$21,381 =	235,191
	\$7,167,655

(4) September 1980 dollars - add 6% for March 1981 dollars.

ETF Conceptual Design 200MWe

Comparison of B&W Scaledown Cost
Corrected for ETF Size/Cost
Compared to AVCO 2X Base Case 1979 Cost

ETF		AVCO 2X Base	
HR/SR Inlet - 132.4 kg/s		130kg/s	
HR/SR MW_t - 378 MW_t		390MW_t(5)	
	(9/80 Cost)	(6/79 Cost)	Mult
Steam Gen. @ 87% =	18,983,000	49,549,000(6)	2.6
Aux. @ 13% =	2,837,000	4,774,000(6)	1.68
	21,820,000	54,323,000	2.5
ESP	6,516,000	6,841,000(6)	1.05

ETF Boiler is 40% of AVCO
ESP is 95% of AVCO

(5) See page 20 of AVCO Report, FE-2614-2
(6) See page 117 of AVCO Report, FE-2614-2

ETF Conceptual Design 200MWe

ETF Cost - for HR/SR
ESP

B&W CSPEC Scale Down - 200MW

$T_{res.}$ = 2-2.24 sec.
Convective Pass Gas Vel. approximately 35-40 fps
Boiler Press - 2150 psi drum press
5:1 recirculation ratio.

Steam Walled:

1) **Furnace Roof**
2) **Pendant Convection Sidewall Tubes**
3) **Horizontal Convection Bank enclosure inlet headers wall tubes and outlet headers**
4) **Primary superheaters bank in convection pass outlet header in paint house to secondary superheater.**
5) **Pendant Secondary Superheater header in penthouse**
   a) **first bank**
   b) **attemperator**
   c) **final bank downstream (gas wise).**

Boiler Dimensions (W X L X H)
Plan - 52'W X 74'L
Front Elev. - Top 52' X 151'H
Bottom 52'W X 20'H
Side Elev. - Top 74'L X 151'H
Bottom 74'L X 20'H

Gas into Boiler - 894,500 lb/hr
- 1,048,589

Gas out Boiler - 1,147,000 lb/hr
- 1,357,352

HP Turbine Inlet - 1,070,992
- 1,017,200 lb/hr — 1000°F-2524 psia

RH Turbine Inlet - 890,500 — 1000°F-531 psia
- 986,470

ETF Conceptual Design 200MWe

True Scale Up Factor= 1.1362
Cost Multiplier = $(1.1362)^{.7}$ = 1.09352

B&W Scale Down		$200MW_e$	GAI ETF Ref.	Mult.
Boiler Inlet Temp/Press/OH		607/2800P/627	636°F/1900P/672	
Gas into Boiler	W	894,500#/hr	1,048,589 (132.4 kg/s)	1.1723
	T	3625	3532	
Boiler Steam Gen.	MW	*247.596	*253.474	
Gas Leaving Boiler	W	1,147,000	1,357,352	1.1834
	T	553	481°F	
	T	3072°F	3051°F	
Steam to S.H. Turbine	W	1,017,200	1,070,992	1.0529
	T	1000/1458	1000/1480	
		ΔH=831	ΔH=808	
	P	2524	1814	
	MW	(Approx. 102.5)	(107.9)	
Steam to RH Turbine	W	890,500	986,470	1.1078
	T	1000	1000	
	P	531	428	
	MW*	(49.8)	*(55.2)	
Oxidant Heater Inlet	W	696,700	867,852	1.246
	T	756°F	432°F	
	P	187.5	72 psia	
Oxidant Heater Outlets	W	696,700	867,852	
	T	1186 (430° ΔT)	1100 (668ΔT)	
	P	175.5	71	
	*Wcp	71,899,440 (21MW)	139,134,033. (40.75 MW)	
Economizer	W =	996,000	1,070,992	
	T =	43°ΔT	80°ΔT	
	*MW =	$14.30MW_t$	$*28.6MW_t$	
	MW =	$187.6MW_t$	232.45	1.24
	*	332.7	378.024	1.1362

ETF Conceptual Design 200MWe

Cost Breakdown Structure (per telecon of March 4, 1981 with V. Pearson, ANL/Tom Buchanon, GAI extension 2677)

a) Title: list the unit-use footnotes to include all major items included.

b) Unit of Measure: list major characteristic - for boiler this is lb/hr of steam, for the ESP it would be the CFM.

c) Material: This includes all material shipped to the site by the vendor. In the case of the HR/SR this includes Engineering, Shop Fabrications, Materials, Pumps, Instrumentation, Prewired electrical etc. - ANY COST INVOLVED IN THE COMPLETE PACKAGE SUPPLIED BY THE VENDOR. - DO NOT INCLUDE FIELD SUPPLIED ITEMS.

d) BOA: Balance of Account: This includes all items supplied in the field-usually by others - i.e. Foundations, Ductwork, Field Wiring, other materials not supplied as part of the delivered package.

e) Installation Costs: All field erection costs - welders, equipment rental, etc.

f) Indirect Costs: To be supplied by GAI

g) Contingencies: Establish contingencies for data supplied GAI will handle the preparation of the final figure.

SCHEDULE: Telecon-- V. Pearson, ANL/R. (Jake) Jacoby, GAI, extension 2643.

ETF Conceptual Design 200MWe

Telecon of March 4, 1981, V. Pearson (ANL)/Fred Wenderoth (B&W)

a) Engineering - covers all engineering from receipt of order.

b) Pumps - should cost of the order of $100,000 or slightly more.

c) Erection - Boiler cost should be 90-95% of figure given ESP 5-10% of figure based on how the ESP is shipped.

d) BRIL - is Brickwork, Refractory, Insulation and Lining installation

e) Service - includes on site field engineer during construction and operating crew required during start-up.

f) Cost-consider the nominal 21 million dollar pro-rated cost to be reasonable and would consider only a 10% contingency would be required for further conservatism.

ETF Conceptual Design 200MWe

HR/SR COST COMPARISON

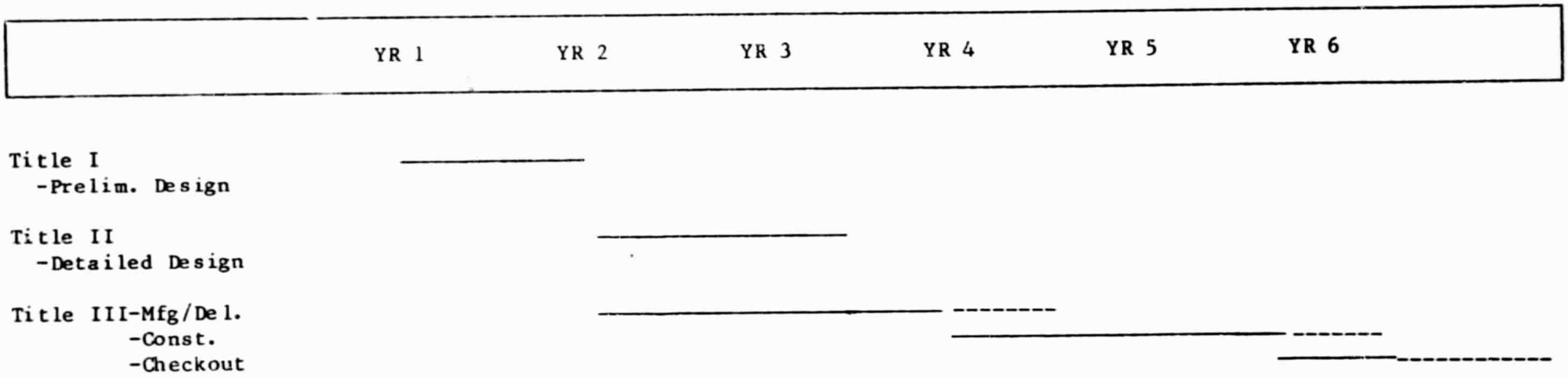
B&W CSPEC	Scale Down	ETF Size Corrected
Boiler	10,500,000 X 1.09352	11,481,960
Accessories	1,450,000 X 1.09352	1,585,604
Add - recirculation pumps @ 100,000-125,000		125,000
Total Material Cost		13,192,564
Erection of Boiler & Associated Structures	7,500,000 X 1.09352	8,201,400
Freight	190,000 X 1.09352	207,769
Service	220,000 -20,000 200,000 X 1.09352	218,704
		8,627,873

Material Cost - $13,193,000
Installation - 8,628,000
$21,821,000 - contingency @ 50% = 10,910,000
New Boiler Vendor Budgeting Cost
$32,731,000

ESP less erection	5,750,000 -150,000 5,600,000 X 1.1254 =	6,302,240
Erection	150,000 X 1.1254 =	168,810
Shipping	est. (20,000) X 1.1254 =	22,500
Service	est. (20,000) X 1.1254 =	22,500
		213,810

Material - $ 6,302,000
Installation - 214.000
$ 6,516,000 - contingency @ 10% = 650,000
Net ESP Vendor Budgeting Cost
$7,200,000

ANL Recommended Schedule-ETF Conceptual Design 200MWe



SOLID LINE - source of schedule, AVCO estimated Schedule for AVCO-100MWe Plant - FE-2614-2
DASH LINE - ANL adjustment
ANL estimate
---- Estimates for Boiler twice as large as AVCO base base.

ANL ETF Subproject Office
HR/SR Schedule Page 1 of 1

5.3 OUTLINES OF PLANS IN SUPPORT OF THE CDER

The outlines of plans required to support the Conceptual Design Engineering Report are described in Sections 5.3.1 and 5.3.2.

A performance assurance program plan with specific provisions for reliability, safety, and quality assurance is normally developed by using the detail design conditions for a given project. This plan is found in Section 5.3.1 and covers those items needed to provide confidence of satisfactory in-service performance.

A plan was also prepared to outline the Environmental Analysis Study required to support the Conceptual Design Engineering Report. This conceptual phase study would precede the Environmental Assessment required by Federal Regulation, 1508.9 Environmental Assessment. This plan is found in Section 5.3.2.

5.3.1 MHD-ETF Performance Assurance (PA) Program Plan

The attached outlilne for a proposed PA program plan was developed as a part of this CDER to provide the basis for the establishment of a PA program to cover design and construction of the MHD-ETF. Such a program must include the actions and responsibilities required to effect the safety, reliability, and quality assurance elements of the project. The basic concept of the program is to ensure that features most important to satisfactory performance be identified and covered by safety and reliability assessments of the probability of their failure, and the consequences of failure.

PERFORMANCE ASSURANCE PROGRAM PLAN OUTLINE

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY (MHD-ETF)

CONCEPTUAL DESIGN - 200 MWe

PREPARED BY

GILBERT ASSOCIATES, INC.

P.O. BOX 1498

READING, PA 19603

MHD-ETF PERFORMANCE ASSURANCE PROGRAM PLAN OUTLINE

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

PERFORMANCE ASSURANCE PROGRAM PLAN

OUTLINE AND CONTENT DESCRIPTION

Section	Title	Description and Content
1.0	PERFORMANCE ASSURANCE PROGRAM	
1.1	AUTHORITY	Statement of authority: The Department of Energy requires a Performance Assurance (PA) Program at all levels and throughout all phases of the project. The PA Program will incorporate Safety, Reliability, and Quality Assurance elements.
1.2	OBJECTIVES	Brief description of objectives: The PA Program is intended to provide maximum reasonable levels of: safety of project personnel and the general public from accidental injury and other hazards associated with construction and operation of the MHD-ETF; reliability of plant and equipment; and all confidence that design, fabrication, construction, and operations activities support these objectives.
1.3	ORGANIZATION	Organization will be discussed from the viewpoint of responsibility, independence, and documentation, as follows:
1.3.1	Responsibility	The prime contractor will be responsible for the establishment and execution of the Project PA Program. The work of establishing and executing the PA Program, or its component parts, may be delegated, but responsibility will be retained by the delegator. Thus, a chain of PA activity may be established through a series of sub-tier contracts, but the prime contractor will remain ultimately responsible.
1.3.2	Independence	PA personnel shall have sufficient authority and organizational freedom to identify problems, suggest solutions and verify implementation of solutions. The relationship of PA functions to design, fabrication, construction, and operations functions throughout the project will ensure

Section	Title	Description and Content
		the independence of Safety, Maintenance, and Quality Assurance from constraints based on cost and/or schedule when these would oppose safety or reliability concerns.
1.3.3	Documentation	The PA Program shall be documented by written policies, procedures, and instructions. These shall identify the activities, structures, systems, and components covered by the PA Program and the authorities and duties of persons and organizations performing activities relating to safety, reliability, and quality assurance. Development of appropriate manuals will be required. A report describing the application of the PA Program to the design, fabrication, construction, and testing of the structures, systems, and components of the facility shall be included in the Preliminary Safety Criteria Report prior to the beginning of construction. A report of the application of the PA Program to the inspection, maintenance, and operation of the facility and to the administrative and managerial controls used to assure safe operation shall be included in the Final Safety Criteria Report prior to operations. The SARs will include Maintenance and Quality Assurance program elements as they relate to safety and reliability.
1.4	INTEGRATION	Safety, Reliability, and Quality Assurance program elements will be complementary, but minimize duplication of effort. Analytical assessments of the consequences of failure will direct activities of all three elements toward the procedures, components, systems, and structures of greatest significance to safety and reliability.

Section	Title	Description and Content
2.0	DESCRIPTION OF PROGRAM ELEMENTS	
2.1	SAFETY	
2.1.1	Introduction	The safety performance assurance program will identify hazards to employees and the public that may be associated with the design, layout, and operation, and provide safety design criteria during early design of the MHD-ETF facility. The program will provide an MHD-ETF Safe Design Criteria reference for guidance during conceptual design, planning, development, acquisition, and layout. By means of this Safe Design Criteria and safety consultation, the program will ensure that: 1. Safety consistent with DOE policies and program objectives is incorporated into project design and operations in timely cost-effective manner. 2. Hazard severity is determined and hazards are identified, evaluated, and eliminated or controlled to an acceptable level throughout the life cycle of projects and/or operations. 3. Historical safety data available from other sources are considered and used where appropriate. 4. Minimum risk is incurred in accepting and using new designs, new materials and components, and in production and testing procedures and operations. 5. Retrofit actions required to improve safety are minimized through the timely inclusion of safety features during early design, development and acquisition. 6. Modifications to accepted designs do not degrade system safety. The safety program shall be appropriately coordinated with the design, layout, and reliability programs.

Section	Title	Description and Content
2.1.2	Program Management	The Safety Assurance Program will be coordinated with the Reliability Program to prevent duplication of effort and ensure full and timely interchange of information. The following major aspects will be addressed in program management, as a minimum: 1. Organization. 2. Tasks, milestones, reports. 3. Incorporation of safety critical items into project cost estimates. 4. Extension of Safety Assurance to major subcontractors. 5. Documentation. 6. Any necessary assignment to subcontractors. 7. Master Safety Assurance File.
2.1.3	Technical Activities	1. An overall Preliminary Hazard Analysis (PHA) will be performed to provide an initial risk assessment of the system and develop the Safe Design Criteria. The proposed design shall be evaluated for hazard severity, hazard probability, risk, and operational constraint. 2. Specific Preliminary Hazard Analyses will be provided as the actual components, systems, pressures, temperatures, and operations are conceived. The "What-If Safety Analysis" shall be applied to all aspects of design, layout, systems, equipment components, installation, testing, startup, and operations. It shall be the responsibility of each contractor and engineer involved as well as those specifically assigned to group task forces to apply the "What-If Safety Analysis" and the Safety Design Criteria to his portion of the work and to its relation to other portions, systems or components. 3. Design engineering shall utilize the Safe Design Criteria to guide their design efforts, aid in identifying the criticality of system elements, and guide them in coordinating their design efforts with the Safety Assurance Program and its hazard risk analysis consulting services. This coordination

Section	Title	Description and Content
		will avoid unnecessary delays and provide timely incorporation of Safety Assurance requirements. It will also provide timely development of Subsystem Hazard Analysis (SSHA). 4. System Hazard Analysis (SHA) will address all subsystem interfaces and determine the safety problem areas of the total system. 5. Operating and Support Hazard Analyses (O&S) will address hazards and determine safety requirements for personnel, procedures, and equipment during installation, operation, and maintenance, testing and modification, transportation and storage, emergency planning, training, and disposal operations.
2.1.4	General Requirements	The Safety Assurance Program will include appropriate levels of analysis of design standards, specifications, regulations, catalysts, feed materials, effluents, materials of construction and by-products; hazardous substances, components, pressures, temperatures, magnetic fields, effects, and operations; human error, safty interlocks, redundancy, fail safe design, system protection, fire detection and suppression, and operating and emergency controls.
2.2	RELIABILITY	The Reliability program element of the PA Program plan will include the following component parts:
2.2.1	Reliability Program Plan	The Reliability Program Plan will address the following subjects: General Requirements Reliability Organization and Functions Reliability Program Control Task Descriptions Schedules Control of Purchased Goods and Services Training of Engineering and Operating Personnel Documentation and Records Program Audits and Evaluation

Section	Title	Description and Content
2.2.2	Reliability, Availability, and Maintainability (RAM) Analysis	A RAM Analysis will be developed including the following aspects: Estimate system availabilities Allocate availability goals among components and subsystems Establish maintenance resources, plans, and off-line time requirements System modelling and reliability prediction
2.2.3	Hazards Analysis	A Hazards Analysis will be planned, covering the following aspects: FMEA and Fault Tree analysis Assess consequences of failures Establish remedial actions Critical Items Lists
2.2.4	Design Activities	The plan will consider the following design activities: Establish RAM requirements for all system components Trade-off studies of design and operations alternatives Design reviews Suggest improvements and follow-up
2.2.5	Procurement Assistance	The following types of procurement assistance will be planned for: Review procurement documents for RAM requirements Subcontractor/Vendor reviews and surveillance
2.2.6	Operations	The following Operations requirements will be included: Prepare maintenance plans and procedures Spare parts analysis and planning System RAM data collection and analysis System change recommendations

Section	Title	Description and Content
2.2.7	Indoctrination and Training	The plan will include indoctrination and training in the following subjects: RAM methods and their limitations for design personnel RAM data requirements for operations personnel Maintenance procedures for operations personnel Reliability consciousness indoctrination
2.3	QUALITY ASSURANCE	
2.3.1	Quality Assurance Program	A Quality Assurance Program will be developed covering the following major parts: General requirements Management review and evaluation Resolution of disputes Classification of structures, systems, and components Quality Assurance organization functions Quality Assurance Program assessment Contractor/Vendor Quality Assurance Program Indoctrination and training Qualifications Controlled conditions
2.3.2	Organization	A plan for Quality Assurance organization will be developed in accordance with Section 1.3, including the following types of organizations and activities: Engineering organizations Quality Assurance organization Review and advisory committees Subcontracted services Stop work authority
2.3.3	Design Control	Design control will be planned to ensure the following aspects are covered: Design organization procedures Design review and verification Design Process Design control program indoctrination Design control records system Plant security design information Degree of independence between design and review personnel

Section	Title	Description and Content
2.3.4	Instructions, Procedures, and Drawings	The Quality Assurance Plan will cover the following aspects of instructions, procedures, and drawings: Content of instructions, procedures and drawings Reviews and verifications Identification system for project drawings
2.3.5	Document Control	The Quality Assurance Plan will provide for coverage of the following types of documents: Quality Assurance Program documents Controlled documents Document change control Control of vendors' drawings Plant security design information
2.3.6	Procurement Document Control	The Quality Assurance Plan will include provisions for the following activities required to control procurement documents: Procurement document preparation Review and approval of procurement documents Control and evaluation of contractor proposals Vendor qualification Lists of bid drawings
2.3.7	Control of Purchased Material, Equipment and Services	Provisions for control of purchased material, equipment, and services will be included in the QA Plan in the following categories: Vendor qualification and history Manufacturing surveillance phase Construction phase Certificates of conformance Documentation requirements
2.3.8	Identification and Control of Materials, Parts, and Components	This subject will be addressed in the following aspects: Identification and control requirements Manufacturing phase Construction phase

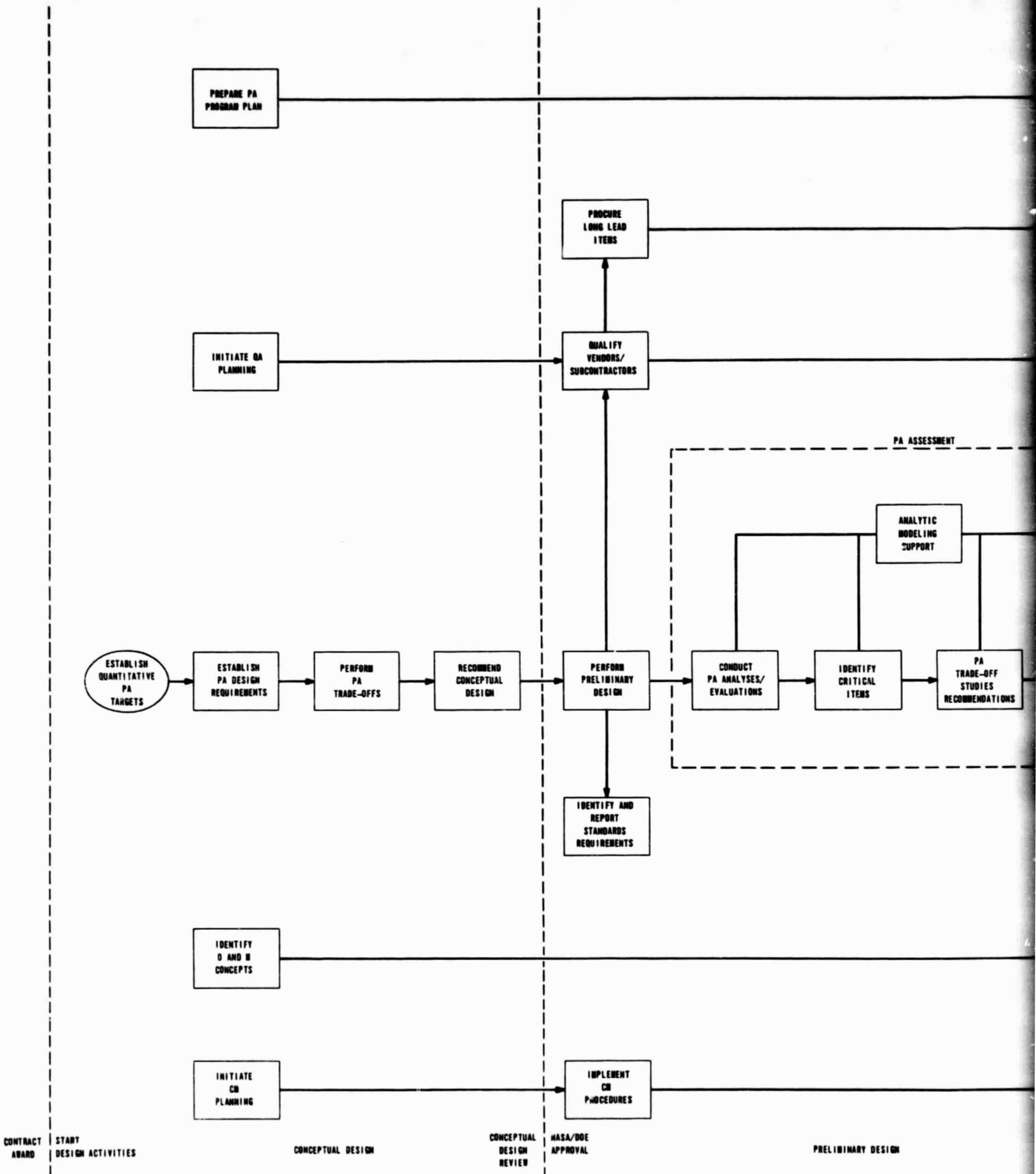
Section	Title	Description and Content
2.3.9	Control of Special Processes	The QA Plan will include requirements for the control of special processes in the following areas, in accordance with industry practice: Special process requirements Supplier controls Qualification records
2.3.10	Inspection	The Inspection portion of the QA Plan will require plans for the following: Inspection program Supplier inspection Construction site inspection Personnel qualification
2.3.11	Test Control	Test control will be planned for in the following areas: Testing requirements Test surveillance
2.3.12	Control of Measuring and Test Equipment	The following subjects will be included in the QA Plan, to cover project requirements, and comply with governmental and industry standards: Requirements Supplier and contractor controls
2.3.13	Handling, Storage, and Shipping	Handling, storage, and shipping of project materials and equipment will be covered so as to comply with governmental, shipping and industry standards: Requirements Controls
2.3.14	Inspection, Test, and Operating Status	The QA Plan will include coverage of the following aspects of inspection, test, and operating status: Requirements Manufacturing phase Construction phase

Section	Title	Description and Content
2.3.15	Nonconforming Materials, Parts, or Components	The QA Plan will provide for identification, segregation, and disposition of these items as follows: Requirements Manufacturing phase Construction phase
2.3.16	Audits	The QA Plan will include a detailed audit plan, including the following aspects: Audit program Personnel training Internal audits External audits Scheduling Audit reports Audit follow-up
2.3.17	Corrective Action	The QA Plan will include provisions for controls on corrective action required, as uncovered in inspections and audits, both internal and external.
2.3.18	Quality Assurance Records	The QA Plan will require a complete system of QA records, including the following aspects: Record requirements Record maintenance Record classification and turnover

Section	Title	Description and Content
3.0	SCHEDULES OF PA ACTIVITIES	Schedules for the Safety, Reliability, and Quality Assurance program elements will be developed, time-phased, as indicated in Sections 3.1 through 3.3.6 below.
3.1	SAFETY	
3.1.1	General	The identification, control, and knowledge of hazardous situations, practices, and procedures shall be emphasized throughout the project to provide exemplary safety assurance.
3.1.2	Conceptual Design Phase	Develop preliminary safety design criteria reference manual. Provide safety assurance consultation.
3.1.3	Title I, Preliminary Design Phase	Issue preliminary safe design criteria reference manual to design, layout, and planning project personnel Review layouts and designs Provide safety assurance consultation Preliminary system safety analysis Preliminary critical items lists
3.1.4	Title II, Detail Design Phase	Provide input to design considerations. Review designs Respond to needs and/or requests for safety and health criteria and data Review QA acceptance criteria to ensure inclusion of safety assurance Provide the appropriate safety analysis to the systems, components and operations Safety Critical Items Lists established
3.1.5	Procurement, Fabrication, and Construction Phase	Provide hazard impact input to environmental impact document Review contracts to ensure inclusion of adequate safety assurance program requirements in construction work
3.1.6	Operations Phase	Provide input, consultation, and/or review of pre-startup testing program Develop safety operating procedures for facility operations Develop and conduct training for operators that includes explanation of hazards and means to eliminate, alleviate, and avoid risks Develop and conduct emergency procedures Develop and conduct first aid training

Section	Title	Description and Content
		Develop and conduct fire brigade training Develop and conduct hazard awareness, identification and reporting training
3.2	RELIABILITY	
3.2.1	General	Indoctrination and training Establish interfaces with safety, quality assurance design and construction personnel
3.2.2	Conceptual Design Phase	RAM program developed Classification criteria reviewed Level of effort for each classification specified Allocation of availability targets
3.2.3	Title I, Preliminary Design Phase	RAM objectives established RAM manuals and procedures developed Preliminary system reliability analysis Preliminary Critical Items Lists Trade-off studies of design alternatives Designs reviewed
3.2.4	Title II, Detail Design Phase	Designs reviewed Acceptance criteria reviewed Failure modes and effects analysis (FMEA) System models and reliability prediction Sensitivity studies Maintainability Reliability Critical Items List established
3.2.5	Procurement, Fabrication and Construction Phase	Reliability critical items reviewed and assessed Maintainability analyzed Procurement documents reviewed Spare parts requirements analysis
3.2.6	Testing and Operation Phase	Data collection and analysis Critical items studies Maintainability Design improvement programs
3.3	QUALITY ASSURANCE	
3.3.1	General	Document control procedures implemented QA programs audited QA personnel trained and qualified Calibration of instrumentation verified Interfaces with safety, reliability, design, and construction personnel maintained

Section	Title	Description and Content
3.3.2	Conceptual Design Phase	QA Program developed Classification criteria defined Level of effort for each classification specified
3.3.3	Title I, Preliminary Design Phase	QA manuals and procedures developed Structures, systems, and components classified Designs reviewed
3.3.4	Title II, Detail Design Phase	Designs reviewed Design procedures audited Acceptance Criteria detailed
3.3.5	Procurement, Fabrication, and Construction Phase	Vendors qualified Procurement documents controlled Vendor/contractor activities surveilled Vendor/contractor programs audited Vendor products inspected and tested Welding and NDT personnel and procedure qualifications verified Construction processes and products inspected Non-conformances identified, segregated, and corrected
3.3.6	Operations Phase	Checklists for pre-startup testing prepared In-service inspection plans developed and implemented Implementation of testing and maintenance programs verified As-built drawings verified Spare parts procurement program implemented



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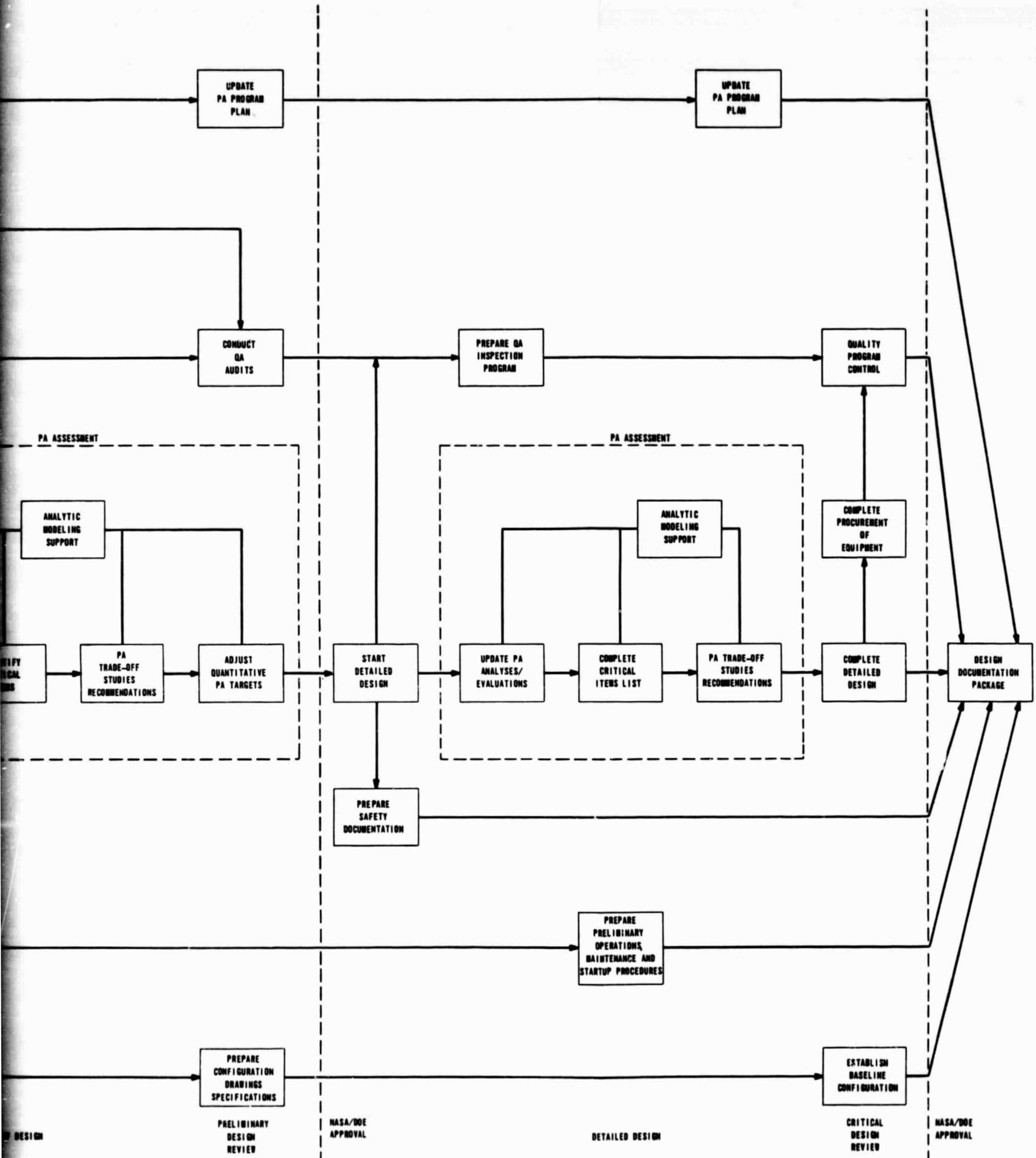

FIGURE 1
PERFORMANCE ASSURANCE DESIGN PHASE ACTIVITIES

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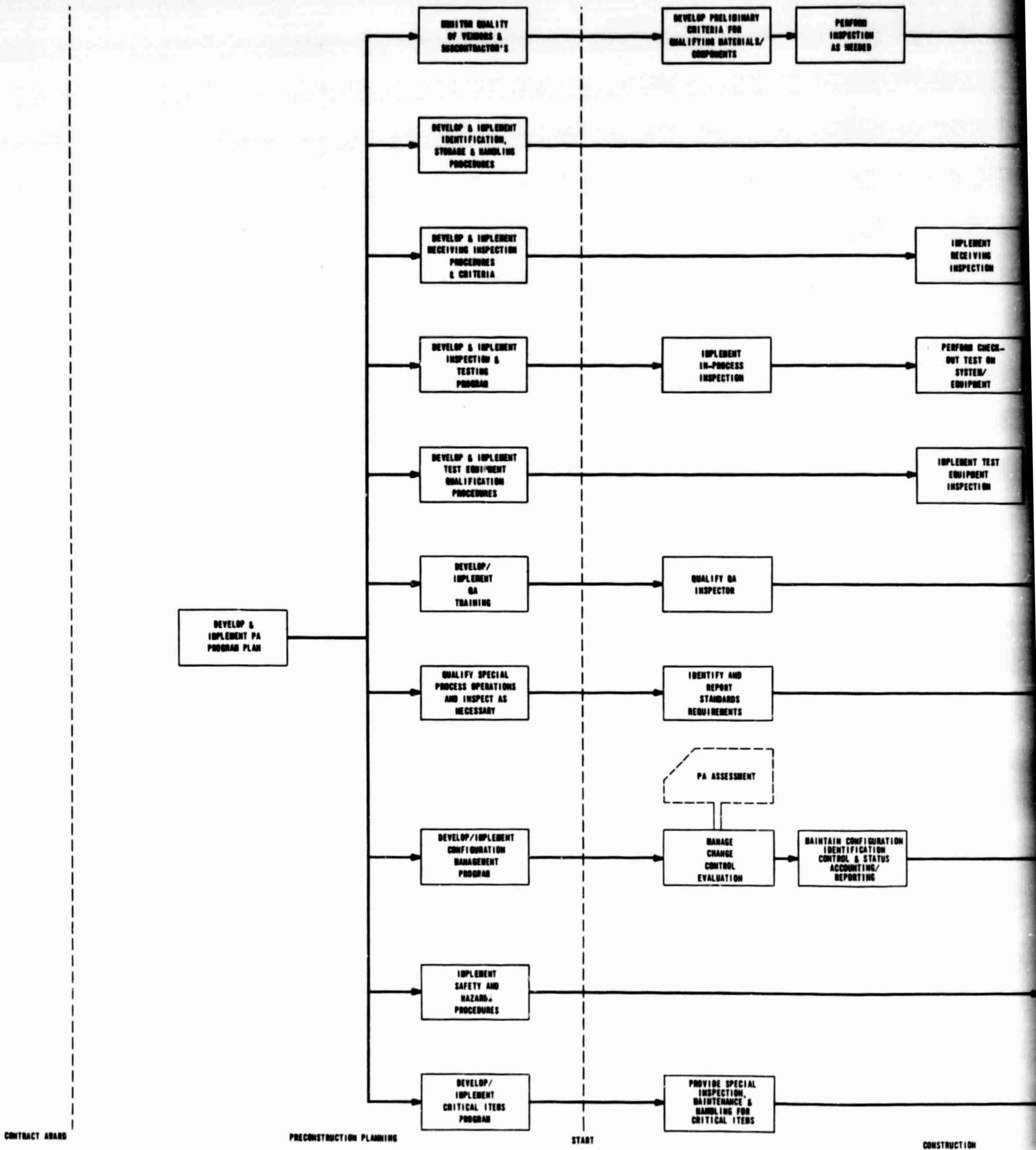

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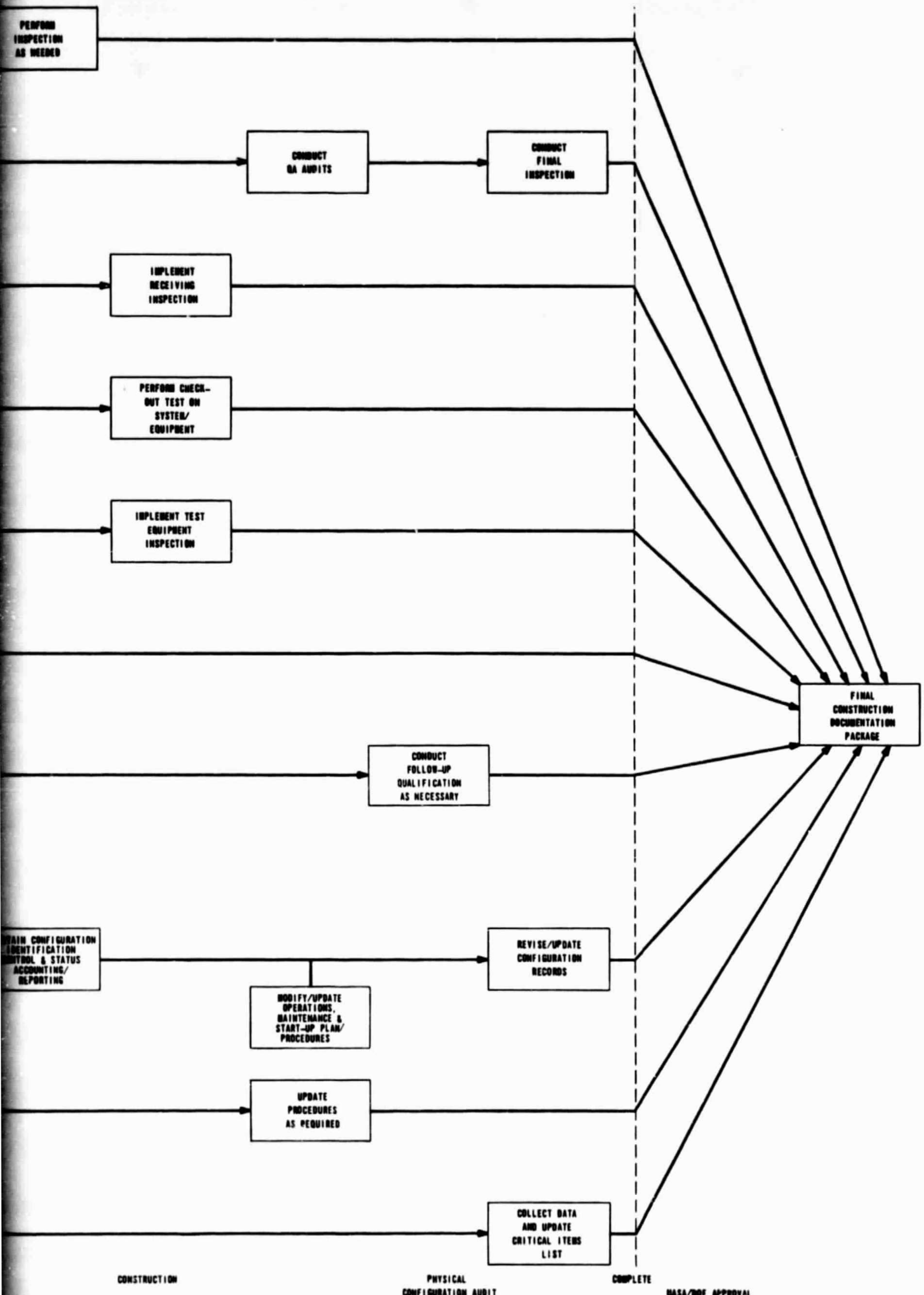

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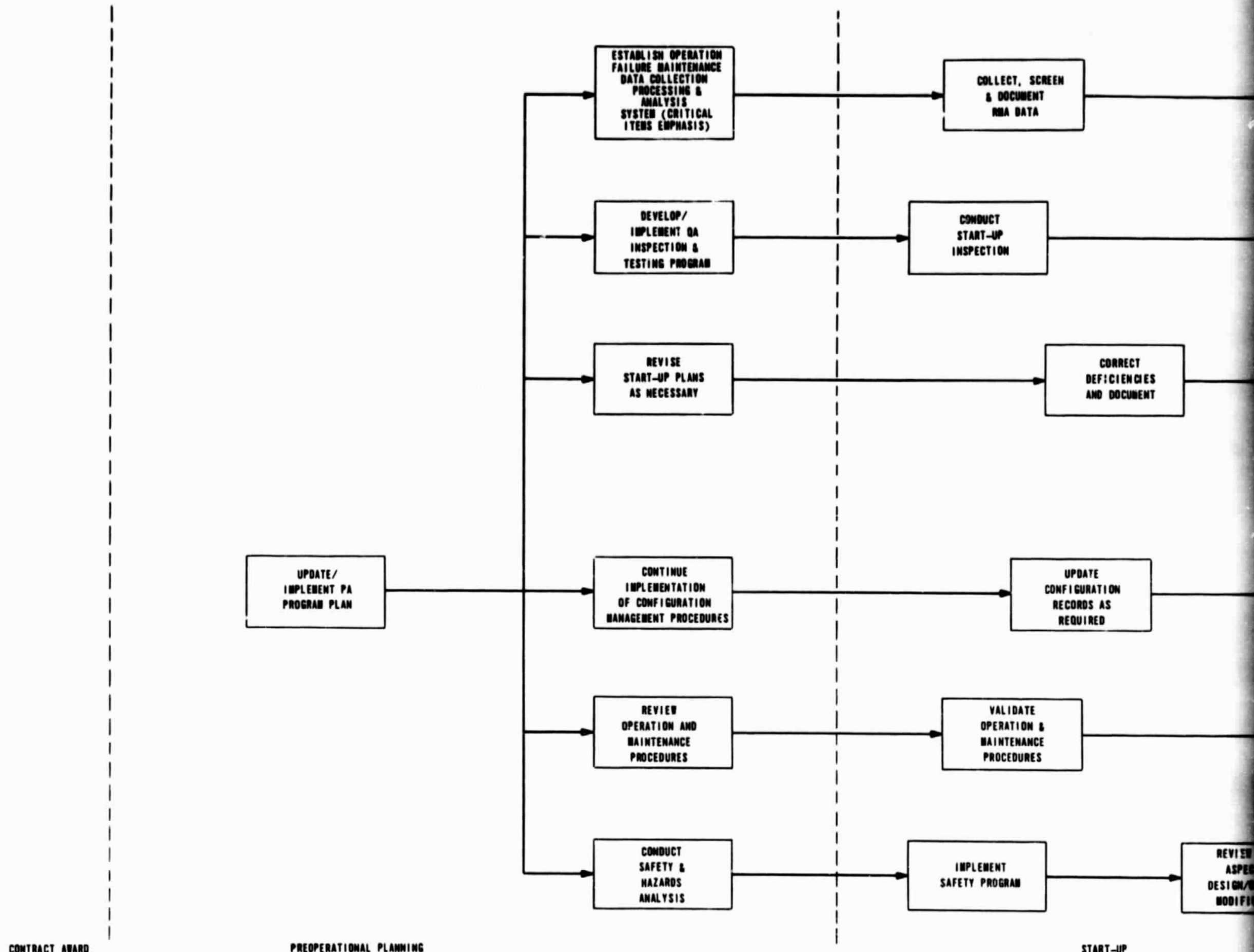
FIGURE 2
PERFORMANCE ASSURANCE CONSTRUCTION AND PROCUREMENT PHASE ACTIVITIES



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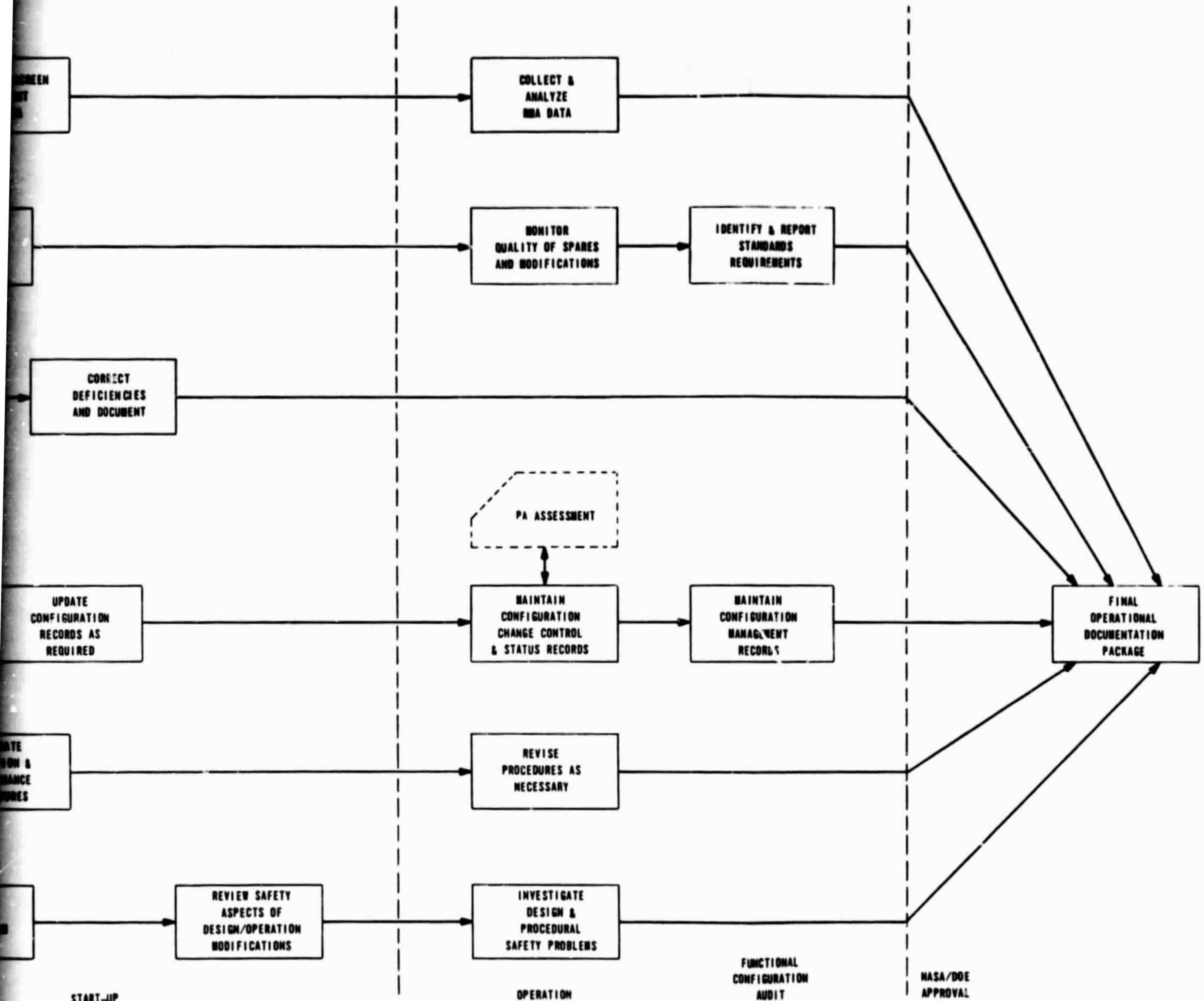

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FIGURE 3
PERFORMANCE ASSURANCE OPERATIONS AND MAINTENANCE PHASE ACTIVITIES

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5.3.2 Plan for the Environmental Analysis Study for the MHD-ETF

The attached Environmental Analysis Study is required to support the Conceptual Design Engineering Report for the 200 MWe MHD-ETF. This conceptual phase study precedes the eventual Environmental Assessment to be prepared in accordance with Federal Regulation, 1508.9 Environmental Assessment. This regulation states:

"1508.9 Environmental assessment.
"Environmental Assessment":

(a) Means a concise public document for which a Federal agency is responsible that serves to:

(1) Briefly provide sufficient evidence and analysis for determining whether to prepare an environmental impact statement or a finding of no significant impact.

(2) Aid an agency's compliance with the Act when no environmental impact statement is necessary.

(3) Facilitate preparation of a statement when one is necessary.

(b) Shall include brief discussions of the need for the proposal of alternatives as required by Sec. 102(2)(E), of the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted."

Under this regulation an Environmental Assessment may be waived in lieu of a determination to prepare an Environmental Impact Statement as specified under Federal Regulation 1508.11-Environmental impact statement.

1508.11 Environmental impact statement.
"Environmental Impact Statement" means a detailed written statement as required by Sec. 102(2)(C) of the Act.

Since the MHD Engineering Test Facility (ETF) is the first-of-a-kind of demonstration facility, it is necessary that the Environmental Analysis Study (EAS) precede the Environmental Assessment and that the determination be legally documented in the Congressional funding phase. The attached provides the recommended format for such a report.

Although a programmatic environmental assessment report was prepared for MHD power plants in their generic form in a report titled, "The Environmental Assessment of MHD Power Plant" (September, 1975) the specific issues relating to any specific plant were not or could not be addressed. It is the purpose of this report, therefore, to perform an environmental evaluation of the ETF on a non-specific site in order to provide an early analysis of the environmental issues when applied to a specific power plant. The environmental analysis study will have the format of the attached. The introductory text has been included with the outline.

Issue Date March 27, 1981
Rev. No. ____________

ENVIRONMENTAL ANALYSIS STUDY

APPROVAL

ANL

D. K. WARINNER (Date)
ANL-Subproject Manager, MHD-ETF

NASA

R. W. BERCAW, Manager (Date)
MHD-ETF Project Office

DOE

M. MINTZ Date)
Systems Engineering Division

J. EPSTEIN (Date)
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D. E. SHELOR (Date)
Acting Chief
Development Engineering Division

K. WOODCOCK (Date)
Acting Deputy Director
Office of MHD

G. RUDINS (Date)
Acting Director
Office of MHD

ANL-ETF Subproject Office

ENVIRONMENTAL ANALYSIS STUDY

Table of Contents

1.0 Introduction

This document is prepared during the course of the development of the conceptual design of the 200 MWe MHD Engineering Test Facility for the purpose of accomplishing two objectives. These are:

a. Assess the potential impact on the environment of this new technology demonstration plant and thereby identify and assess problem areas requiring further technological development.

b. Provide a mechanism for identifying and establishing specific design standards for those plant components and systems, and their interfacing auxiliary system performance, whose design may be controlled by national standards for protection of the environment.

1.1 Scope

The National Environmental Policy Act of 1969 has made the protection of the environment a matter of law. Section 102 of the Declaration of National Environmental Policy states the following:

> "Sec. 102. The Congress authorizes and directs that, to the fullest extent possible: (1) the policies, regulations and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act, and (2) all agencies of the Federal Government shall-
>
> (A) utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment;
>
> (B) identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by title II of this Act, which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making along with economic and technical considerations;
>
> (C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on-

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by section 552 of Title 5, United States Code, and shall accompany the proposal through the existing agency review processes;

(D) study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources;

(E) recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment;

(F) make available to States, counties, municipalities, institutions, and individuals, advice and information useful in restoring, maintaining, and enhancing the quality of the environment;

(G) initiate and utilize ecological information in the planning and development of resource-oriented projects; and

(H) assist the Council on Environmental Quality established by title II of this Act."

ENVIRONMENTAL ANALYSIS STUDY

FOR

MAGNETOHYDRODYNAMIC

ENGINEERING TEST FACILITY (MHD-ETF)

CONCEPTUAL DESIGN - 200 MWe

PREPARED BY

ARGONNE NATIONAL LABORATORY

MARCH 27, 1981

The 200 MWe MHD-Engineering Test Facility, funded by the U. S. Government to demonstrate the commercial readiness of this new energy system, is required to meet the rules and regulations that have been promulgated under this law.

The new technology associated with this new energy system brings together a new set of conditions, both internal and external to the plant, that have no precedent in other energy systems operating to date.

Although a programmatic environmental assessment report was prepared for MHD power plants in their generic form in a report titled, "The Environmental Assessment of MHD Power Plant" (September, 1975), the specific issues relating to any specific plant were not or could not be treated.

It is the purpose of this environmental report, therefore, to evaluate the environmental impact of the non-specific site ETF. This provides an early assessment of the environmental issues when applied to a specific power plant.

1.2 Basis for Consideration

This Environmental Analysis Study is prepared to produce a document which precedes, and lays the foundation for, the Environmental Assessment Report (EAR). The EAR will be prepared in accordance with Federal regulation, 1508.9 Environmental Assessment, which states:

> 1508.9 Environmental assessment.
> "Environmental Assessment":
>
> (a) Means a concise public document for which a Federal agency is responsible that serves to:
>
> (1) Briefly provide sufficient evidence and analysis for determining whether to prepare an environmental impact statement or a finding of no significant impact.
>
> (2) Aid an agency's compliance with the Act when no environmental impact statement is necessary.
>
> (3) Facilitate preparation of a statement when one is necessary.
>
> (b) Shall include brief discussions of the need for the proposal of alternatives as required by sec. 102(2)(E), of the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted.

Under this regulation an Environmental Assessment may be waived in lieu of a determination to prepare an Environmental Impact Statement as specified under Federal Regulation 1508.11-Environmental impact statement.

> 1508.11 Environmental impact assessment.
> "Environmental Impact Statement" means a detailed written statement as required by Sec. 102 (2)(C) of the Act.

In the case of 200 MWe MHD-ETF, the sheer size of the facility and the type and amounts of influents and effluents have been summarily judged to preclude the alternative to the EIS: namely, the Finding of No Significant Impact (FONSI) (Sec. 1508.9(a)(1)). Irrespective of the merits of such an early judgement for a new facility employing new technology in the initial stages of conceptual design, the fact remains that the Environmental Analysis Study offers the mechanism for documentation of the environmental considerations and requirements for such plant. It is on this latter basis that the decision to prepare a formal Environmental Analysis Study was made.

This study will attempt to identify, quantify, and compare, where possible, the known factors affecting the environment with the potential plant emissions, site conditions, and operating requirements in compliance with Federal Regulations. Site Impact Evaluation cannot be made, since the ETF project has not selected a site for the ETF. Therefore a list of site requirements (assuming compliance with federal regulations) will be used to compare the hypothetical site data being used by the project with the federal regulations to minimize the plant's environmental impact in general.

As indicated in the table of contents, this report addresses three major areas:

A. A description of the plant, its emissions, and the requirements for acceptable emissions release.

B. A description of the fictitious site and an assessment of the requirements for the ultimate selection of a site.

C. A discussion of the alternatives available to the whole problem of siting a new-technology demonstration facility.

2.0 General Description of the Engineering Test Facility (ETF)

The following description is excerpted from project documents. It constitutes a summary description of material presented in greater detail in the ETF Design Requirements Document (DRD), the ETF Systems Design Descriptions (SDD), and the Conceptual Design Engineering Report (CDER).

2.1 Integrated Plant

2.1.1 General ETF Description

The ETF, as described in the Magnetohydrodynamics (MHD) Program Plan, is a fully integrated commercial prototype MHD power plant of nominal 200 MWe net output. Performance of this plant under commercial power generation conditions should meet or surpass existing utility standards for fuel, maintenance, and operating costs; plant availability; load-following capability; safety; and durability. The plant should also meet or surpass all applicable federal, state, and local environmental regulations. The objectives for the MHD ETF are:

1. To demonstrate and test an integrated, combined coal-fired MHD/steam system supplying power to a grid, which is prototypic of an early commercial plant;

2. To demonstrate the high availability features of the plant design;

3. To evaluate component interactions, control characteristics, and performance capabilities;

4. To demonstrate the environmental acceptability of the plant.

Figure 1 illustrates the arrangement of the ETF.

2.1.2 Facility Narrative

The Engineering Test Facility will be a prototype coal-fired based-load electric generating plant with a nominal electrical output of 200 MW. The plant will consist of an MHD topping cycle integrated with a steam bottoming cycle. It will be a complete plant which delivers electricity to a utility grid.

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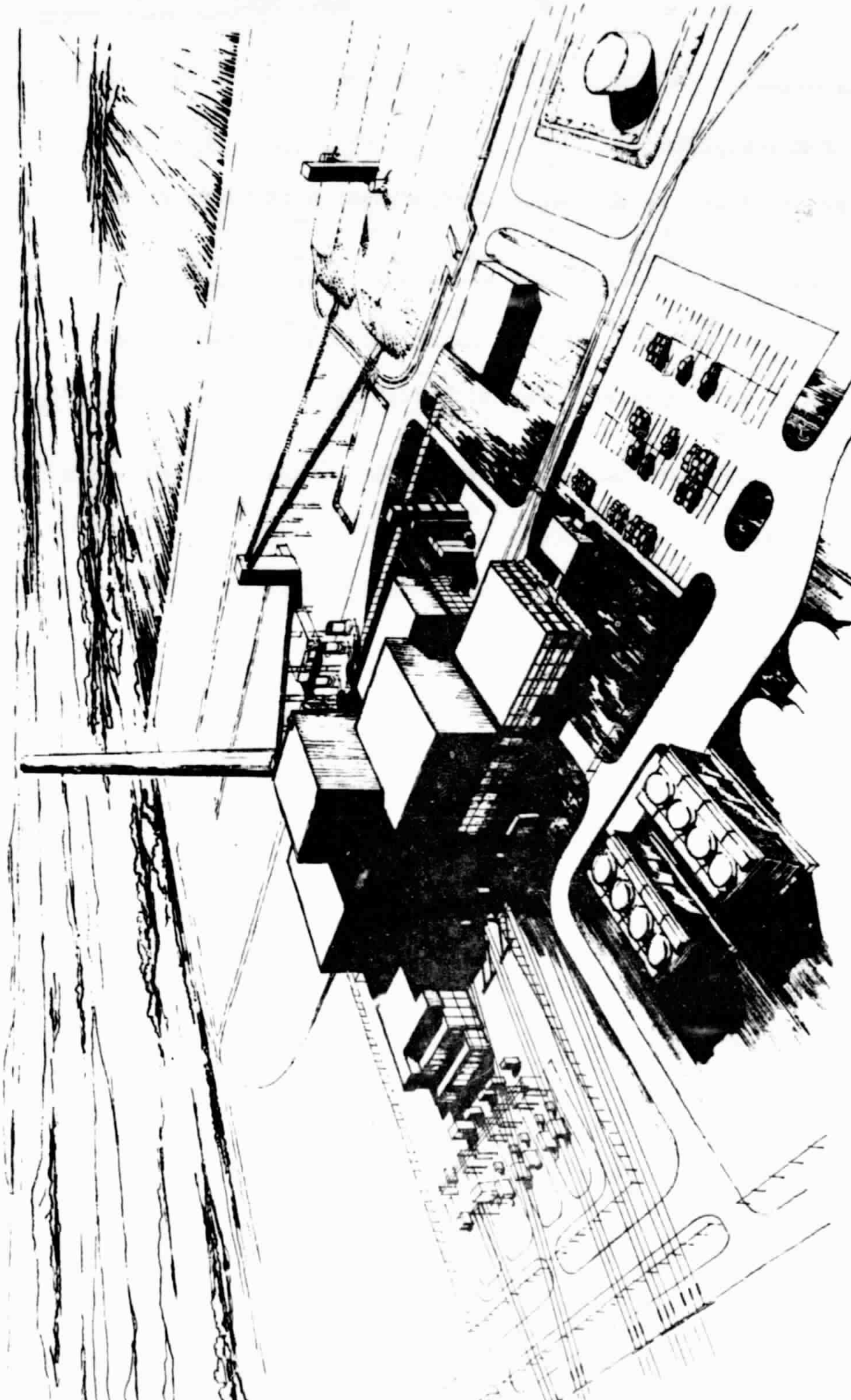


MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
200 MWe POWER PLANT
FIGURE 1
VIEW FROM NORTHEAST

The ETF will demonstrate the commercial viability of the MHD process for the generation of power from coal. The MHD process directly produces electrical energy by the movement of an electrically conducting fluid through a magnetic field. In a coal-fired MHD power plant, the gases formed by the combustion of coal are made electrically conductive by "seeding" them with a potassium salt at extremely high temperatures. The resulting plasma is then directed through a tube called the channel where it performs the same function as the copper armature in a conventional generator. The electrical currents induced in the gas or plasma stream are led out to an external load through electrodes placed in the walls of the channel. The net result is that part of the energy of the gas stream is converted into electricity.

An MHD generator essentially combines the functions of the steam turbine and electrical generator employed in a conventional system. Because the energy of the gas stream is converted directly to electrical energy, an MHD generator is, in principle, a much simpler device than the conventional turbogenerator. The generator consists of the channel with an appropriate array of electrodes and insulators, located within a magnetic field. It has neither the highly-stressed moving parts of a turbogenerator, nor any solid parts that are not readily accessible for external cooling; thus, it can withstand temperatures well beyond the capabilities of conventional turbines. As a consequence of high-temperature operation, power plants incorporating MHD generators are potentially more efficient than conventional turbine power plants.

The MHD Power Train consists of the MHD generator, a coal combustor and nozzle, and an inverter. A superconducting magnet surrounding the channel provides the magnetic field needed for power generation. Coal is burned in the combustor with the pressurized oxidant to produce a high temperature gas. This gas is ionized by the addition of potassium seed in the form of a mixture of potassium salts. It is then accelerated by a nozzle to near sonic velocity and discharged into the MHD channel where both thermal and potential energy are used to generate DC electrical power by the magnetohydrodynamic process. The power is collected by a set of channel wall electrodes, consolidated, and then inverted from DC to AC for transmission to the distribution network. The diffuser improves the performance of the generator by converting the kinetic energy of the high velocity gas leaving the channel to increase the static pressure.

Coal, seed and oxidant are supplied to the MHD power train combustor by independent systems. The oxidant must provide a combustion temperature which is adequate to ionize the seed. It is obtained by mixing air with oxygen from an on-site Air Separation Unit (ASU) and is then compressed and then heated by the MHD exhaust gas to an intermediate temperature.

Considerable energy is contained in the MHD exhaust gas. The ETF utilizes most of it to generate steam which is used to drive a turbogenerator, providing additional electrical power, and drive the air- and oxidant compressors and other auxiliary equipment.

The ETF uses nonconventional processes to control emissions of sulfur and the NO_x formed during combustion. The sulfur combines preferentially with the potassium seed to form particulates which are removed from combustion gases by conventional methods. Recovered seed can be reused once it has been reprocessed to remove the sulfur, but reprocessing facilities are not included in the ETF. NO_x emissions are limited by sub-stoichiometric (fuel rich) combustion followed by a time controlled temperature reduction of the exhaust gases that allows the NO_x to reduce to a low concentration.

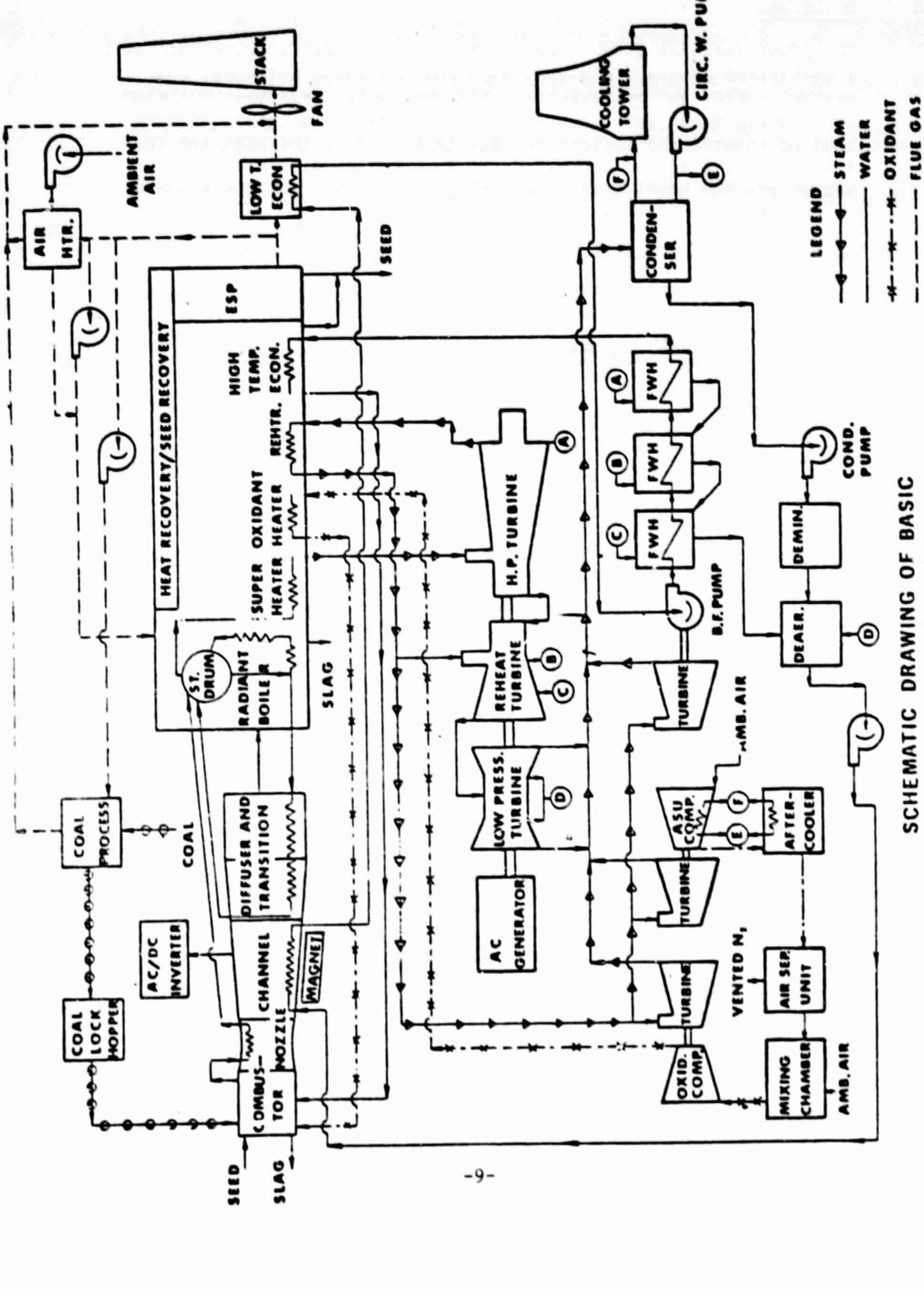
The ETF resembles a coal-fired steam power plant in many ways. It is analogous to a conventional plant which has had the coal combustor replaced with the MHD power train. Most of the ETF components are conventional. They may, however, be sized or configured differently or perform additional functions from those in a conventional coal power plant. For example, the boiler performs not only its usual function of providing steam, but also the functions of heating the MHD oxidant, recovering seed, and controlling emissions.

2.1.3 Identification of Plant Systems

The ETF is organized into a number of systems, each performing one or more specific functions. Related systems are grouped together in separate sections of the DRD. These sections are:

Oxidant Supply
MHD Power Train
Magnet
Heat Recovery/Seed Recovery Boiler
Steam Power Train
Plant Auxiliaries
Plant Services

The functions and design requirements of the Oxidant Supply, MHD Power Train, Magnet, Heat Recovery/Seed Recovery, Steam Power Train, Plant Auxiliaries, and Plant Services systems, are presented in DRD Sections 5 through 11. These sections expand the detail of performance requirements presented in DRD Section 3. The arrangement of these systems, except for plant auxiliaries and services are illustrated in Figure 2.



SCHEMATIC DRAWING OF BASIC
ETF CONFIGURATION

FIGURE 2

2.1.4 Buildings

The plant includes structures and buildings normally associated with a coal-fired generating plant; such as, a turbine building, coal system control and preparation buildings, water treatment building, circulating water pump house, industrial waste treatment building, cooling towers, and various storage tanks. Also included are the structures for an air separation unit, a building to house the magnet and MHD power train, and related ancillary structures needed to complete the facility.

The character and appearance of the plant resembles those of conventional fossil power plants.

2.1.5 Design Performance and Requirements

Plant Type

The ETF will be a baseload plant.

Plant Rating

Power	200	MWe Net (Reference)
Voltage	TBD	kV (± TBD kV (to be compatible with utility grid))
Frequency	60	Hz -1% to 0%, three phase
Duration	TBD	hrs continuous operation at rated conditions

Plant Fuel

The plant will be designed to burn coal from the Montana Rosebud (MR) seam.

As received coal properties include:

H_2O	27% maximum
Ash	12% maximum
Sulfur	1.1% maximum
HHV	11,500 BTU/lb., typical dry

Load Range

The ETF Plant shall be able to operate over a range from 75% to 100% of the (reference) plant rating.

Plant Regulation and Response

Regulation range:

75% to 100% of (reference) plant rating.

Load following:

The power plant will be able to reduce power output from rated load to 75 percent of rated load and increase the power output from 75 percent of rated load to rated load at rates of at least 3 MW per minute.

Frequency Control:

When the ETF is connected to the grid system and the grid frequency deviates from 60 Hz by more than ± five (5) percent, the ETF shall be separated from the grid for unit protection. Should either duration of operation below 57.5 Hz be indeterminate or frequency fall below 57 Hz, the unit shall be tripped.

A deviation greater than 0.06 percent of frequency (equal to deadband) shall be cause for stably restoring response within 0.2 seconds.

Design operation at steady state shall be based on frequency changes not in excess of +0.02 Hz, -0.04 Hz exclusive of dead band. Deadband shall not exceed 0.036 Hz.

Stability:

The MHD/steam generating unit shall be designed to be inherently stable under all conditions of manual and automatic control while connected to the grid system. Operation of this unit shall not be curtailed by characteristics of other grid units.

Load Regulation:

The power plant will be able to accommodate load changes about steady state power levels at rates of at least 3 MW per minute.

Plant Efficiency

	100% Rating (REF)	75% Rating
Net overall (minimum)	38%	TBD
MHD topping cycle (minimum)	TBD	TBD
Steam bottoming (minimum)	TBD	TBD

Lifetime

The ETF shall be designed and constructed in accordance with utility practice for a thirty-year life. The number of operating cycles to be assumed for design calculation purposes is TBD.

Availability/Reliability

The overall plant shall have at least a 75% availability level when operating under commercial power generation conditions.

Operational Modes

The commercial prototype of the ETF will be expected to operate as a baseload power plant. However, the ability to handle multiple startups and shutdowns annually is important in selecting and designing power equipment.

Cold Startup:

Typical startup sequence will include, but not be limited to:

Cold Flush
Hot Cleanup (Waterside)
Combustor Light-Off
Boiler Start
Turbine Start
Turbine - Generator Synchronization
Turbine - Generator Load
Synchronize MHD Generator
Load MHD Generator

Baseload:

This represents 100 percent of nameplate load on turbine generators operating continuously on the utility grid. With no load variation, the operators primarily monitor system performance.

Part-Load:

The unit has the ability to maintain output over a range of 75 percent to 100 percent of nameplate load. Maximum and minimum loads are limited by:

Equipment capability
Temperature effects
NO_x control
Heat sink

Standby:

This implies a no-load condition of readiness for the plant to be placed in the operating mode. Two basic modes of standby are the hot and cold condition. Typical hot standby conditions are:

Major components (turbine, boiler, etc.) temperatures are held as high as possible to reduce thermal warming time to operating conditions.

Main turbine is on turning gear with sealing steam supplied from auxiliary steam system.

Condenser vacuum is maintained and circulating water pump(s) operate.

System water cleanup continues.

Startup air heaters operate.

Air and gas flows are minimal.

Fuel and oxidant systems are ready to operate.

All auxiliaries are ready or operating.

Typical cold standby conditions are:

Equipment is allowed to cool, but is still ready for operation.

System water cleanup may be operating.

Cooling water system and other auxiliary systems are either operating or ready to operate.

Cold startup may begin at any time.

Shutdown:

This mode of operation is the transition between the operating and standby modes. Typical shutdown event sequences include, but are not limited to:

Reduction of load uniformly between MHD and steam turbine generators.

Control of cooling water, gas, and air flow reduction to prevent extreme thermal stresses.

Conversion to air oxidant.

Reduction and cessation of fuel flow.

Startup and shutdown of oil burners (vitiator air heaters).

Turbine trip, coast down, and placed on turning gear.

Shutdown of support systems and auxiliaries as no longer required.

Emergency Shutdown Mode:

(TBD)

Breach of Security:

(TBD)

Miscellaneous Events:

Any event for which procedures have not been prepared and which (in the opinion of responsible plant operators) poses a threat to personnel or major equipment shall justify a shutdown.

2.1.6 Testing

All systems and subsystems shall be tested to assure compliance with plans and specifications in a manner consistent with the usual acceptance requirements for this type of equipment. In addition the specialized testing of the following listed MHD hardware is TBD:

MHD Power Train
Magnet
Heat Recovery and Seed Recovery

2.1.7 Environmental

The ETF complies with federal, state, and local standards for air, water, and solid waste management.

2.1.8 Design Codes and Standards

The design shall be in accordance with nationally recognized codes and standards. State and local site codes shall apply. Codes listed in the subsequent parts of this document are representative of codes utilized in the design. The listings should not be construed as complete.

2.1.9 Performance Assurance Program Plan

A plan shall be developed for the preparation of an ETF Performance Assurance Program (PAP). The program shall detail actions and responsibilities to be used to provide confidence of satisfactory in-service performance. The basic concept of the program shall be that features most important to satisfactory performance be clearly identified and receive special attention. Important features shall be identified by safety and reliability assessments of the probability of failure and the consequences of failure.

Safety

The system safety program plan will identify hazards to personnel and the public, equipment and property that may be associated with the ETF design, layout, and operation, and will provide safety design criteria during the early design of the facility.

The ETF shall comply with the following safety standards:

Occupational Safety and Health Standards, Department of Labor, 29 CFR 1910.

Interim Standards for Occupational Exposure to Magnetic Fields, Memorandum July 23, 1979, E. Alpen, Lawrence Berkeley Laboratory to K. Baker, Division of Safety, Standards and Compliance, U. S. Energy Research and Development Administration.

Reliability

The reliability program plan will identify reliability, availability, and maintainability of the systems and components.

Quality Assurance

Appropriate actions shall be taken during design and construction to assure that the level of quality of the design, manufacture, and installation of all systems, equipment, and structures is in accordance with the requirements of the Quality Assurance Program Plan.

2.2 ETF/Environmental Interface

The interface of the ETF with the environment exists at the buildings, ETF grounds, storage tanks, silos (seed), equipment, storage areas (coal), cooling tower, electric power input and output transmission lines, all ETF effluent and waste system discharge points, material/resource input and delivery points to the ETF

systems, road/rail transportation systems, and surrounding communities.

The interface exists during ETF construction, testing, and plant operation. Attributes which will be considered in the environmental evaluation of the ETF include air, water, land, ecology, sound, thermal pollution, and human and economic factors. A site requirement list will be prepared for the ETF. The ETF conceptual design and interfacing systems will be evaluated to identify potential environmental problems and issues. As a minimum, areas listed in the following subsections will be evaluated.

2.2.1 Water Supply Systems

The water supply system for the ETF site (non-specific) can originate from a city water supply, lakes, rivers, streams, and/or ground water. The study will identify and quantify pollutants and evaluate ETF water requirements and potential environmental impact. This would include type and frequency of water usage, water chemistry and purity, required water pretreatment, type and frequency of liquid discharge from the ETF, required waste water treatment, thermal pollution, potential contamination of source water, etc.

Potential problems will be identified and environmental issues will be listed.

2.2.2 Fuel and Seed Supply Systems

Liquid fuels, coal, and seed will be supplied to operate the ETF plant. The study will evaluate effect of transport of these materials to the ETF, on-site storage, on-site processing, and supply of these materials to the using components. Points of consideration will include method and frequency of transport, material quantities, storage facilities (size, location, and type), type of contaminants, and method of processing.

2.2.3 Air and Gas Supply Systems

Compressed service-air and instrument-air, liquid oxygen, and nitrogen are produced on-site and are used in the ETF. Industrial gases such as carbon dioxide, helium, and hydrogen are procured and delivered to the site. This study will evaluate and identify potential problems and issues of on-site production, delivery of industrial gases, gas storage, and use of these working fluids. The study will consider process details, storage and location, usage, delivery cycles, and gas quantities.

2.2.4 Waste Heat Rejections

Waste heat from the ETF will be rejected to the environment from the stack, cooling tower, ventilation systems, and effluent cooling water. The study will evaluate and identify the potential problems and environmental issues related to ETF thermal output to the environment. As a minimum this will include range of discharge temperatures from each source, rate of heat rejection, and schedule.

2.2.5 Waste Product Storage and Disposal

The study will identify, classify, and characterize the solid (includes particulates), liquid, and gaseous wastes generated in the ETF. Storage of these materials and disposal will be evaluated. Potential problems and environmental issues will be identified. As a minimum this study will consider slag, spent seed, fly ash, spent chemicals, waste (spent) resin, contaminated water, pollutants, sewage waste leakage, and effects of accidents (e.g. spillage etc.). This shall consider waste quantities, location, method of storage, method of disposal, method of treatment, type of contaminants, type transportation, and frequency of disposal.

2.2.6 Waste Gas Treatment

Waste gas generated in the ETF and all effluent discharge to the environment shall be characterized relative to composition, including particulate matter. This shall consider NO_x, SO_2, flue gas, and particulate matter in the gas stream. The study shall evaluate quantities of gases generated, method of waste gas treatment, amounts converted in the process to nonemission classification, method of removing solids from gas stream, and composition of the gas discharged to the stack. Potential problems and environmental issues will be identified.

3.0 Plant Emissions and Effluent Standards

3.1 Emissions

The emissions from the ETF are to meet the Environmental Protection Agency (EPA) New Source Performance Standards of June 1979. For example, for the atmosphere, these standards include:

(a) Exiting particulate: (max permissible) 0.03 lb. per million BTU input and 1% of potential combustion concentration and 20% opacity (6 minute average).

(b) Sulfur dioxide (SO_2): 1.20 lb. per million Btu input and 90% reduction of potential combustion SO_2 concentration on a 30-day rolling average. When emissions are less than 0.60 lb. per million Btu, the reduction is 70%. The percent reduction is computed on the basis of overall SO_2 removed, including that removed with seed, in the ash, or by the Coal Management System. Removal percentage rate is indicated on Figure 3.

(c) Nitrogen oxides (NO_x): Based on the combustion of Montana Rosebud (subbituminous B) coal, the process shall be controlled such that the NO_x emissions do not exceed 0.50 lb. per million Btu heat input. Continuous compliance with the standard is required, based on a 30 day rolling average. Also, percent reduction in uncontrolled NO_x emission levels are required, but not controlling. Thus, compliance with the emission limit will assure compliance with the percent reduction requirements.

3.2 Effluent Standards

The effluents will meet applicable effluent standards.

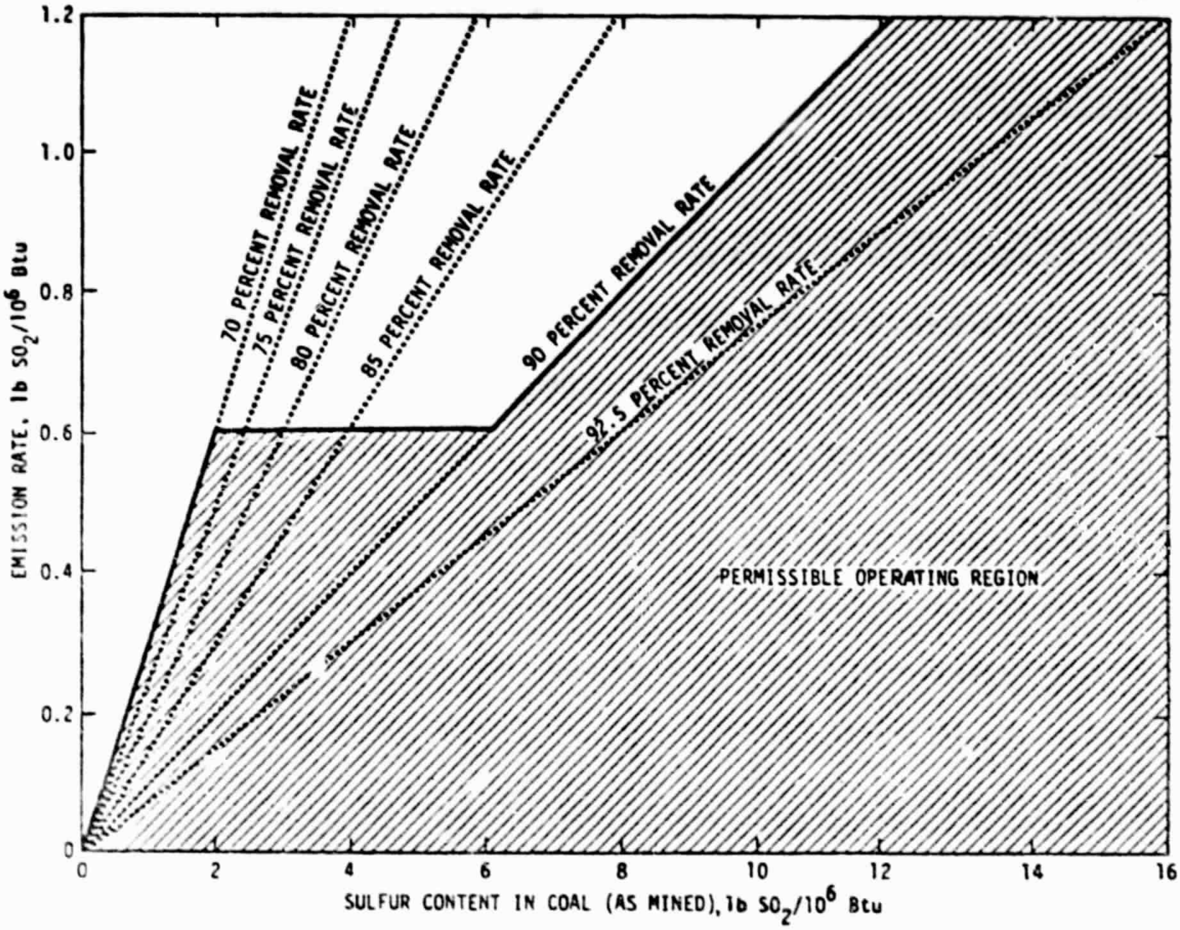


Figure 3 Influence of sulfur in coal on required SO_2 removal efficiency.

4.0 Generic ETF Site Description

The ambient design conditions for the ETF are listed in Table 2.1.

TABLE 2.1
AMBIENT DESIGN CONDITIONS

	Dry Bulb Temp. °F	Wet Bulb Temp. °F	Pressure psia
Plant Design Point	42	36	13.0
Summer Design Point	80	59	13.0
Winter Design Point	-7	-8	13.0

These conditions are typical sites located in Montana. The region is characterized by plains, widely dissected by streams and having strong local relief of 5-50 ft.

The hypothetical site is relatively large and flat and located 10 miles from the nearest town. Relatively flat areas of up to 1000 acres are available.

The socioeconomic impact of ETF construction and operation will be considered.

The hypothetical site location contains a transportation system, composed of railroads, an airport, and federal and state highways. Access to the site is provided by constructing an access road which connects to a major highway. Railroad access is provided by constructing a spur line to a major railroad line within five miles of the site location. All plant shipments for both construction and operation, including fuel delivery, are assumed to be overland.

Power for construction will be available at the hypothetical site from the local electric utility. Water for construction and operation activities will be obtained from a surface source within one mile of the hypothetical site location.

In the vicinity of the hypothetical site, it has been found that calm wind periods account for nearly one-third of the observation during the morning and early afternoon, and for one-fourth of all observations. The remainder of the time, the wind blows from all sectors with similar frequencies. Average wind speeds are 20 mi/hr during unstable conditions and 4 mi/hr during stable conditions. Northwesterly winds prevail.

Table 2.2 lists the design meteorology history for the hypothetical ETF site. An altitude of 3300 ft. above sea level is assumed.

The hypothetical site is located in seismic zone 2 and contains alluvial fill to depths of 500 ft. or more. The fill rests on an irregular bedrock surface of moderate relief. This alluvial is a poorly sorted mixture that ranges from fine silty clay to boulders and conglomerates. The alluvial fill at the site is highly permeable. The site presents no serious problems either for site preparation by grading or for construction of facilities.

TABLE 2.2

WEATHER DATA (HYPOTHETICAL SITE)

Dry Bulb Range °F	Hrs/Year	Mean Wet Bulb °F
100-104	1	63
95-99	10	62
90-94	57	61
85-89	132	60
80-84	202	59
75-79	282	57
70-74	393	55
65-69	484	53
60-64	617	50
55-59	730	47
50-54	839	44
45-49	855	40
40-44	857	36
35-39	787	32
30-34	679	29
25-29	476	25
20-24	349	21
15-19	216	16
10-14	181	11
5-9	159	6
0-4	151	2
-5 to -1	119	-3
-10 to -6	91	-8
-15 to -11	57	-13
-20 to -16	23	-18
-25 to -21	14	-23
-30 to -26	4	-28
-35 to -31	1	-32

5.0 Summary Environmental Analysis Study

A summary of the study will provided. The summary will define the compliance of the ETF with the Federal standards and identify potential problems and environmental issues.

6.0 Alternatives

The non site-specific Environmental Analysis Study will not address alternatives.

APPENDIX 7.1

REFERENCE DRAWINGS

(Applicable Drawings Contained in the CDER)

Number	Title
8270-1-210-007-001	Plot Plan
8270-1-240-002-001	Yard Coal Handling
8270-1-240-002-002	Yard Coal Handling
8270-1-240-002-003	Seed Unloading and Storage Area
8270-1-240-002-004	Seed Unloading and Storage Area
8270-1-571-302-201	Circulating and Service Water
8270-1-403-302-321	Boiler Flue Gas
8270-1-582-302-161	Plant Makeup Water
8270-1-641-302-371	Plant Industrial Waste
8270-1-644-302-381	Sanitary Waste
8270-1-652-302-242	Miscellaneous Gases
8270-1-540-314-001	System Heat and Mass Balance
8270-1-550-318-001	Water Balance

APPENDIX 7.2

APPLICABLE DOCUMENTS; BIBLIOGRAPHY

Title	
MHD-ETF Design Requirements Document	DOE/NASA/10769-20 NASA TM-82705 September 1981
MHD-ETF Conceptual Design Engineering Report	DOE/NASA/0224-1 NASA CR-165452 September 1981
National Environmental Policy Act of 1969	---------
Federal Regulation - Environmental Assessment	No. 1508.9
Federal Regulation - Environmental Impact Statement	No. 1508.11
Dept. of Labor, Occupational Safety and Health Standards	29CFR1910
Interim Standards for Occupational Exposure to Magnetic Fields; E. Alpen, Lawrence Berkeley Laboratory to K. Baker, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration	Memo, July 23, 1979
Environmental Protection Agency, New Source Performance Standards	June 1979

(Others TBD)

APPENDIX 7.3

ENVIRONMENTAL ASSESSMENT REPORT

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5.4 DESIGN DETAILS

5.4.1 Equipment List

A detailed listing of equipment is not normally provided for the conceptual design phase of a project. For the detail design effort, an equipment list would be developed which would be used for (1) verification of total equipment requirements, (2) estimating total equipment costs, and (3) guidance in following equipment delivery schedules. Detailed information for listed equipment, such as, system, quantity, tag number, location by building, bill of material number, and manufacturer's drawing number would be included. For this CDER, listings of major equipment are provided in the individual System Design Descriptions, which are included in Section 5.5 of this report.

5.4.2 Electrical Load List

A detailed listing of electrical loads is not normally provided for the conceptual design phase of a project. The major part of a load list is usually the tabulation of motors required for driving pumps, fans or compressors. For these motors, the load list would provide detail design information, such as, motor type, quantity, horsepower, connected bus voltage, running KVA, bill of material number, and manufacturer's drawing number. For the ETF conceptual design, electrical loads are shown schematically on the One Line Diagrams, GAI Drawing Nos. 8270-1-802-206-001, -002, and -003. These diagrams are attachments to the Electrical System Design Description (SDD-801), which is included in Section 5.5 of this report.

5.4.3 Water Balance

The water balance diagram is a schematic representation of (1) all input sources of water to the plant, (2) major plant uses of this water, and (3) all discharge paths of water from the plant. The water balance for the ETF plant is shown on GAI Drawing No. 8270-1-550-318-001. This drawing is included in the listing of related drawings under Section 2.8 of this report.

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5.5 SYSTEM DESIGN DESCRIPTION

System Design Descriptions (SDDs) supporting the design of the MHD-ETF facility are listed below. A copy of each system design description is provided in this Section, including associated fluid system diagrams and other drawings.

SDD AND ASSOCIATED DRAWING LIST

SDD No.	System Design Description	Drawing Title	Drawing Number
011	MAIN & REHEAT STEAM (TURBINE-GENERATOR)	Main & Reheat Steam	8270-1-501-302-011
031	STEAM BYPASS & STARTUP	Steam Bypass & Startup	8270-1-504-302-031
041	EXTRACTION STEAM	Extraction Steam	8270-1-503-302-041
051	AUXILIARY STEAM	Auxiliary Steam	8270-1-507-302-051
081	BOILER FEEDWATER	Boiler Feedwater	8270-1-521-302-081
101	CONDENSATE	Condensate	8270-1-511-302-101
111	FEEDWATER HEATER DRIPS	Feedwater Heater Drips	8270-1-525-302-111
113	FEEDWATER HEATER & MISC. DRAINS, VENTS & RELIEFS	Feedwater Heater Vents, Drains and Reliefs	8270-1-525-302-113
		Miscellaneous Drains	8270-1-519-302-121
131	CONDENSER AIR REMOVAL	Condenser Air Removal	8270-1-491-302-131
161	PLANT MAKEUP WATER	Plant Makeup Water	8270-1-582-302-161
181	SAMPLING	Sampling	8270-1-633-302-181
201	CIRCULATING WATER	Circulating and Service Water	8270-1-571-302-201
231	CLOSED CYCLE COOLING WATER	Closed Cycle Cooling Water - Turbine and Compressor Building	8270-1-531-302-231
		Closed Cycle Cooling Water - HR/SR Area and MHD Building	8270-1-531-302-232
241	INDUSTRIAL GAS SYSTEMS	Plant Service and Instrument Air Supply	8270-1-652-302-241
		Miscellaneous Gases	8270-1-652-302-242
281	FUEL OIL	Fuel Oil	8270-1-413-302-281
321	BOILER FLUE GAS	Boiler Flue Gas	8270-1-403-302-321
		Afterburner Gas Supply	8270-1-403-302-322
		Coal Drying and Transport Gas	8270-1-403-302-323
341	COAL MANAGEMENT	Coal Feed Lock Hoppers	8270-1-410-302-341
		Yard Coal Handling - Plan and Section	8270-1-240-002-001
		Yard Coal Handling - Plan and Sections	8270-1-240-002-002

SDD AND ASSOCIATED DRAWING LIST (Cont'd)

SDD No.	System Design Description	Drawing Title	Drawing Number
342	SEED MANAGEMENT	Seed Feed Lock Hoppers	8270-1-410-302-342
		Ash/Seed Removal From Power Systems (Flue Gas Cleanup)	8270-1-451-302-352
		Seed Unloading and Storage Area - Plan	8270-1-240-002-003
		Seed Unloading and Storage Area - Section	8270-1-240-002-004
351	SLAG MANAGEMENT	Slag Handling	8270-1-451-302-351
371	PLANT INDUSTRIAL WASTE	Plant Industrial Waste	8270-1-641-302-371
		Sanitary Waste	8270-1-644-302-381
401	FIRE SERVICE WATER	Fire Service Water	8270-1-781-902-401
501	OXIDANT SUPPLY	ASU (Air Separation Unit) Compressor, Steam Turbine Drive Process & Instrumentation P&I #1	1-FS-813
		Alternative ASU Compressor Electric Motor Drive P&I #2	1-FS-814
		Air Separation Unit (ASU) P&I #3	1-FS-815
		Mixing Chamber P&I #4	1-FS-816
		Liquid O_2 & N_2 Storage and Vaporization P&I #5	1-FS-817
		Oxidant Compressor Steam Turbine Drive P&I #6	1-FS-818
		Oxidant Compressor Electric Motor Drive P&I #7	1-FS-819
		Block Diagram	1-FS-820
		Drawing Symbols and Drawing List	1-FS-822
		Plan Compressor Building	1-LO-1577-1
		Plan-Cold Boxes & Equipment	1-LO-1577-2
		Plan-LOX Vaporizer & LOX Storage Area	1-LO-1577-3

SDD AND ASSOCIATED DRAWING LIST (Cont'd)

SDD No.	System Design Description	Drawing Title	Drawing Number
		Plan-Air Filters, Aftercooler & Oxidant Mixing Chamber	1-LO-1577-4
		Elevation "A"-"A" Turbines & Compressors	1-LO-1577-5
		Elevation "B"-"B" Turbines & Compressors	1-LO-1577-6
		Elevation "C"-"C" Cold Boxes & Equipment	1-LO-1577-7
		Oxidant Mixing Chamber Plan, Elev. & Details	1-LO-1577-8
		Compressor Bldg. Plan Utility Piping	1-LO-1577-9
502	MHD POWER TRAIN	Drawing Index	SDD-1100
		MHD Power Train System Assembly	SDD-1101
		MHD Power Train System Facility and Support Structures P&E	SDD-1102
		MHD Combustor P&E	SDD-1200
		MHD Channel Support Structure Assembly - P&E	SDD-1300
		MHD Channel Support Structure P&E	SDD-1301
		MHD Diffuser P&E	SDD-1400
		MHD Diffuser Cross Section	SDD-1401
		MHD Diffuser and Transition Section Support Structure P&E	SDD-1402
		MHD Control Subsystem and Interface Block Diagram	SDD-1500
		Consolidation Network Connection Diagram	SDD-1501
		Consolidation Network Detail - 5 Stage Anode Consolidation	SDD-1502

SDD AND ASSOCIATED DRAWING LIST (Cont'd)

SDD No.	System Design Description	Drawing Title	Drawing Number
		Consolidation Network Detail - 3 Stage Cathode Consolidation	SDD-1503
		Consolidation Network Detail - Make Up Current Distribution	SDD-1504
503	MAGNET	Drawing Index	D4429
		Field Profile and Bore Dimensions	D4439
		Outline	D4441
		Foundation	D4443
		Fringe Magnetic Field Zone Boundaries	D4444
		Plan and Elevation, Magnet and Accessories	D4445
		Limits on Variations in Magnetic Field Profile and Field in Channel Cross-section	D4448
		General Assembly	D4450 Sh. 1-4
		Diagram, Helium Piping	D4452
		Diagram, Nitrogen Piping	D4453
		Diagram, Electrical Power Supply and Discharge System	D4454
		System Diagram (Schematic)	D4456
		Typical Joint in Superconducting Cable	D4457
504	HEAT RECOVERY/SEED RECOVERY	(None)	
505	INVERTER	(None)	
701	HEATING, VENTILATING, & AIR CONDITIONING	HVAC - Chilled Water	8270-1-721-902-001
		HVAC - Steam - Hot Water	8270-1-722-902-001
801	ELECTRICAL	Primary Power	8270-1-802-206-001
		4160V Power	8270-1-802-206-002
		480V Power	8270-1-802-206-003

SYSTEM DESIGN DESCRIPTION

SDD-011

MAIN AND REHEAT STEAM SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-501-302-011

R. B. Jensen Feb. 5, 1981

SYSTEM ENGINEER DATE

T C Reitz Feb 27, 1981

REVIEWED DATE

APPROVED DATE

Revision: 1
Date: September 25, 1981
Approved: [signature]

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
MAIN AND REHEAT STEAM SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Main and Reheat Steam System as shown on Fluid System Diagram 8270-1-501-302-011, Main and Reheat Steam. It includes the functions, details of components, controls and instrumentation, operating modes, design, safety, and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Main Steam System is designed to convey high pressure and temperature steam from the Heat Recovery/Seed Recovery (HR/SR) Superheater outlet to the High Pressure (HP) turbine section in a single pipe, branching to two leads and terminating at the turbine stop valves.

The Reheat Steam System is designed to convey steam from the HP turbine exhaust to the Reheater section of the HR/SR, and from the Reheater outlet to the Intermediate Pressure (IP) turbine and mechanical drive turbines.

1.2 SYSTEM INTERFACES

The major components of the Main and Reheat Steam System are the Superheater and Reheater sections of the HR/SR, main and reheat piping and valves, the steam turbine generator, the Hot Reheat steam supply to the Oxidant Air Compressor turbines, Air Separation Unit (ASU) Air Compressor turbine and the Boiler Feedwater Pump turbines. Other systems which interface with Main and Reheat Steam are the Steam Bypass and Startup, Sampling, Auxiliary Steam, Miscellaneous Drains and Vents, and the Extraction Steam System.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and the system limits to be used in the selection of the required components. Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures, temperatures, and "pipe sizing" flow rates are taken from the plant system heat balance diagram and tabulated on the Fluid System Diagram 8270-1-501-302-011, Main and Reheat Steam. Flow rates are those occurring during turbine valves wide open with the HR/SR steam outlet at Maximum Continuous Rating (MCR) conditions. Main and Reheat Steam System pipe sizing is based on pressure drop and a steam velocity which is limited to 1,000 feet per minute per inch of internal pipe diameter. The Main Steam System piping is designed for a total pressure drop of approximately 96 psi at MCR, while limiting steam velocity to 15,000 feet per minute. The Reheat piping is also limited to 15,000 feet per minute velocity. These are approximate values. Initial design of Reheat piping allows for a total of approximately 44 psi drop in the Reheat Steam System piping, subdivided as follows:

Cold Reheat Piping	7 psi
Reheater	22 psi
Hot Reheat Piping	15 psi

The final design of the Main and Reheat Steam System piping will depend on an economic optimization of pipe sizing and pressure drop.

2.0 DESIGN DESCRIPTION

The Main and Reheat Steam System consists of piping, valves and controls. The major equipment associated with the system noted in Section 1.2 are covered in other System Design Descriptions.

2.1 SUMMARY DESCRIPTION

The Main Steam System is capable of passing 1,071,000 pounds per hour of steam at 1,895 psig and 1,005°F at the superheater outlet of the HR/SR. The steam from the Superheater is combined into a single pipe which branches into two pipes leading to the stop valves of the HP turbine. This arrangement is used to distribute the flow while maintaining zero temperature differential at the turbine. The two main steam pipes are provided with warmup and drain connections. The warmup piping interfaces with this system and is described in System Design Description, Feedwater Heater and Miscellaneous Drains, and shown on Fluid System Diagram 8270-1-519-302-121, Miscellaneous Drains.

A steam bypass system, provided for unit startup and for control of steam flow on trip conditions, interfaces with this system and is described in System Design Description, Steam Bypass and Startup, and shown on Fluid System Diagram 8270-1-504-302-031.

Superheat steam temperature is controlled by spraying boiler feed pump discharge water into the system with desuperheaters which are located between the primary and secondary superheaters.

The exhaust from the HP turbine (Cold Reheat) is combined into a single pipe and returned to the HR/SR for reheating. The Cold Reheat piping is sized for minimum pressure drop, permitting a higher percentage of the allowable drop in the Hot Reheat piping. A branch connection from the Cold Reheat piping supplies extraction steam to feedwater heaters 4A and 4B. A large drain pot

is located at the low point of the Cold Reheat pipe where condensation or spray water may accumulate and be discharged automatically. The Hot Reheat System piping combines the piping at Reheater outlet into a single pipe and branches to two pipes leading to the IP turbine stop valves, and pipes supplying the mechanical drive turbines.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment components shown on the Main and Reheat Steam Diagram are the Superheater and Reheater sections of the HR/SR, the high pressure, intermediate pressure and low pressure sections of the main turbine, mechanical drive steam turbines, and branches to the bypass system and feedwater heaters 4A and 4B. Items not described here are described in the following System Design Descriptions:

Item	System Design Description	Fluid System Diagram
Steam Bypass & Startup	Steam Bypass & Startup System	8270-1-504-302-031
Feedwater Heaters	Boiler Feedwater System	8270-1-521-302-081

2.2.1.1 Turbine Generator

Type: Tandem compound, two casing, two flow exhaust, single reheat, with direct connected 153,653 KVA hydrogen cooled generator.

Guarantee rating	128,044	kW
Speed	3,600	rpm
Throttle, inlet pressure	1,800	psig
Throttle, inlet temperature	1,000	^{o}F
Reheat temperature	1,000	^{o}F
Throttle flow	1,070,992	lbs/hr
Exhaust pressure	2.0	In. Hg. abs.
Number of extractions	4	

Generator rating	**153,653**	**kVa**
Generator voltage	**22**	**kV**
Generator power factor	**0.9**	
Generator short circuit ratio	**0.58**	
Generator gas press.	**30**	**psig**

2.2.1.2 Turbine Generator Accessories

The turbine generator equipment will include accessories normally provided by the turbine generator manufacturer. These include: a lubrication system with oil tank, pumps, filters, heat exchangers, piping and controls; a hydrogen gas cooling system with heat exchangers, controls and piping; a seal oil system with tank, pumps, separators, filters, heat exchangers, piping and controls; a steam sealing system with steam seal regulator (controls), steam seal condenser/exhauster, control valves and piping; a bus duct cooling system; and an excitation system.

2.2.1.3 Superheater

Flow	1,070,992	lbs/hr
Pressure	1,895	psig
Temperature	1,004.9	^{o}F

2.2.1.4 Reheater

Flow	986,470	lbs/hr
Inlet pressure	436	psig
Inlet temperature	649.3	^{o}F
Outlet pressure	414	psig
Outlet temperature	1,001.2	^{o}F
Reheater system press. drop	44	psi

2.2.2 Piping and Valves

Main and Reheat Steam System piping is chromium-molybdenum alloy steel and carbon steel designed and manufactured in accordance with the standards listed in Section 1.3.1. Stop valves and control valves, provided by the turbine manufacturer, are located at the inlets to the HP and IP turbines. Safety

valves, provided by the HR/SR manufacturer, are located at the Superheater outlet headers, the radiant boiler steam drum, and the Reheater inlet headers. Removable blocking devices are located in the Reheat lines for use in initial steam blowout.

The Main and Reheat Steam System piping is designed with welded joints in accordance with ANSI B31.1. Valves are forged alloy steel or carbon steel with weld ends and designed in accordance with ANSI B16.34.

Piping materials are in accordance with the following:

System	Material-ASTM No.
Main Steam	Chrome Moly Steel - A335
Cold Reheat	Carbon Steel - A106
Hot Reheat	Chrome Moly Steel - A335

Valve body materials are compatible with pipe materials.

2.2.3 Electrical

Motor-operated valves are 460 volts, 3 phase, 60 Hertz, with power supplied from 480 volt motor control centers. Solenoid valves will be coordinated with instrumentation power sources.

The main generator will deliver 153,653 KVA at 22 kV, 3 phase and 60 Hertz via bus duct to switchgear for the main plant distribution transformer. Power for the turbine generator will be fed back to the turbine switchgear control panel.

2.2.4 Instruments, Controls, and Alarms

The Main and Reheat Steam System is provided with appropriate instrumentation for sensing flow, pressure and temperature at points commensurate with good design practice to monitor system performance.

Level control instrumentation is provided for maintaining design water level in the Radiant Boiler drum. Feedwater control and drum level controls keep enough water entering the drum to produce the steam being released.

A drain pot is provided on the low point of the cold reheat line with level switches and automatic drain control. The drain pot is provided with a a diaphragm-operated automatic level control valve. This level control valve is opened for startup and no-load operation of the main steam turbine. This valve automatically closes above 20 percent (rising) load. There are two level switches on the drain pot. One is for high level which will over-ride automatic closure and open the valve. If the level continues to rise, the second switch sounds an alarm in the control room, and initiates water induction prevention features. To maintain the drain pot free of condensate during normal operation, the automatic drain valve is bypassed with a continuous drain orifice. The drain orifice prevents nuisance alarms by allowing small flows to pass avoiding accumulation.

Provisions are made for obtaining analysis samples from the steam drum, the superheater inlet, the main steam header, cold reheat header and the hot reheat header.

The operation and control of the Main and Reheat Steam System is affected by other systems and equipment supplied by the HR/SR and turbine manufacturers. Those systems are described in Section 1.2.

The equipment, piping, and controls for these systems are covered in the manufacturer's instruction books and certified drawings. Alarms, controls, and permissives associated with those systems are covered in this SDD only to the extent that these devices interface with other equipment in the main or reheat steam system, or signal the main control room for alarm or indication.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits and protective devices will be described and included in System Design Descriptions noted in Section 1.2.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required. The major equipment have safety and relief valves or expendable metal diaphragms. The HR/SR and the steam turbine generator are extensively protected by devices supplied by the manufacturers.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Main and Reheat Steam System other than those normally associated with high pressure and temperature equipment and piping.

3.3 PRECAUTIONS

Startup, operation, and shutdown must be in accordance with instructions received from manufacturers furnishing equipment for this system.

The prevention of turbine induction water damage and boiler/turbine temperature mismatches are covered in other System Design Descriptions and in manufacturer's instructions.

After periods of layup and prior to startup it is essential that all steam system drain valves be opened.

4.0 MODES OF OPERATION

4.1 STARTUP

Coordination of metal temperatures in the HR/SR, main steam turbine, and steam piping is of primary importance in order to limit thermal stresses which result from temperature mismatches. The temperature of the turbine prior to

startup may be at any level between room temperature and rated temperature. The HR/SR can be under a widely varying set of initial pressure conditions, which affect the conditions of the steam supplied. Because of the numerous possible startup conditions, general categories are covered: startup, normal operation and shutdown.

Any starting situation is preceded by first aligning the system for normal operation. This would include, but not necessarily be limited to, the following:

1. **Preboiler cycle cleanup to acceptable purity conditions.**

2. **HR/SR filled and vented at startup drum level.**

3. **Operational boiler feed, condensate, and circulating water systems.**

4. **The main steam turbine is placed on turning gear and is rolling prior to admitting gland sealing steam and establishing a vacuum.**

5. **Auxiliary Steam System is functional for initial deaeration, turbine seals and for system warmup.**

6. **Main condenser vacuum is established as low as possible, but not greater than 5.0 inches Hg. Abs.**

7. When main steam pressure reaches 200 psig minimum, the stop valve bypasses are opened to initiate prewarming the HP turbine casing, reducing turbine thermal stresses. This is done while the turbine is on turning gear. Throughout the turbine prewarming operation, turbine casing metal and differential temperatures are monitored, recorded and maintained according to the limits set by the turbine manufacturer.

8. During HR/SR warmup operation, boiler blowdown is monitored to check acceptable solids concentration levels. Steam piping is warmed, with all drains opened, as steam pressure increases.

9. The turbine may be rolled off turning gear when the inlet steam conditions at the turbine throttle valves are approximately 600 psig with 100°F of superheat. This will provide optimum uniform heating and differential expansion rates dictated by the turbine manufacturer.

10. The turbine is accelerated to a rotor warming speed and held until the unit is satisfactorily pre-warmed. Acceleration may then continue to 3600 rpm, and the turbine synchronized and loaded.

4.2 NORMAL OPERATION

The normal load range of the overall plant is categorized as base load with very little part load operation below 75 percent. The plant is capable of operating satisfactorily and with no special operator action in the event of small load changes. During normal operation the overall plant is controlled

and monitored from the main control room. Should the load go below 70 percent administrative action would be required to decide what percentage of the load the topping side or bottoming side would share; whether the bypass system should be initiated; whether the turbine and steam piping drains are to be opened; or lastly, if the unit should be tripped.

4.3 SHUTDOWN

While on the bypass system and during an operator-initiated shutdown, the plant is brought down to minimum load, and the turbine is tripped.

During the shutdown process, it is imperative that the turbine drains and main steam and reheat startup drains be opened to drain all moisture from the steam lines.

In a normal, controlled shutdown the steam line drain valves open at about 20 percent turbine generator load. On a turbine generator trip the non-return valves in the feedwater heater extraction lines will close automatically and drain valves open automatically. Operator attention is required to confirm operation of these valves.

During long periods of shutdown, the HR/SR and main steam piping should be blanketed with nitrogen to reduce the formation of corrosion products which can cause increased maintenance problems.

4.4 SPECIAL OR INFREQUENT OPERATION

During periods of operation below 75 percent plant load it is up to the judgement of the control room operators to continue operation by utilizing the Steam Bypass System up to the full capacity of the system, or go into a controlled shutdown mode. Below (TBD) percent load the unit must go into a controlled shutdown mode.

Most of the steam plant equipment is redundant or can be bypassed if problems develop. If bypassed equipment upsets the performance of the unit or tends to degrade the life of other apparatus, then the control room operators should consider reducing turbine generator load, or proceed into a shutdown mode.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

An in-house computer system will monitor significant data points in the Main and Reheat Steam System to parallel the automatic controls. This will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance shall be carried out on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

The Superheater, Reheater, feedwater heaters, steam turbines and all piping, valves, controls, gauges, pipe supports etc., shall be inspected periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., depending on the recommendations of the equipment manufacturer. In general, the part will be replaced during planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT

SYSTEM DESIGN DESCRIPTION

MAIN AND REHEAT STEAM SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Main and Reheat Steam	8270-1-501-302-011

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Extraction Steam

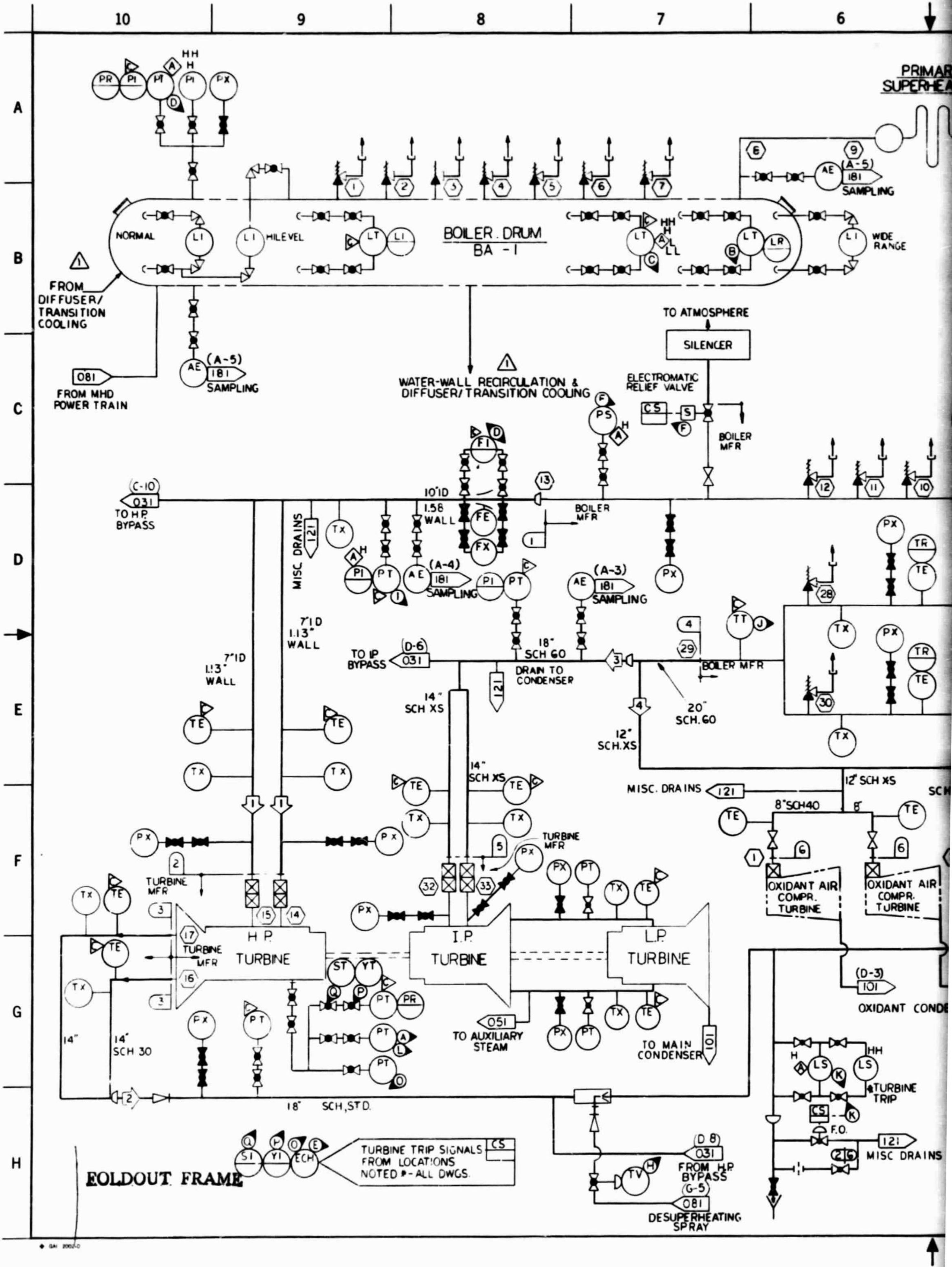
Auxiliary Steam

Boiler Feedwater

Miscellaneous Drains & Vents

Plant Heat & Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001

ASME Standard No. TDP-1-1980 "Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation"; Part 1 - Fossil Fueled Plants



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A
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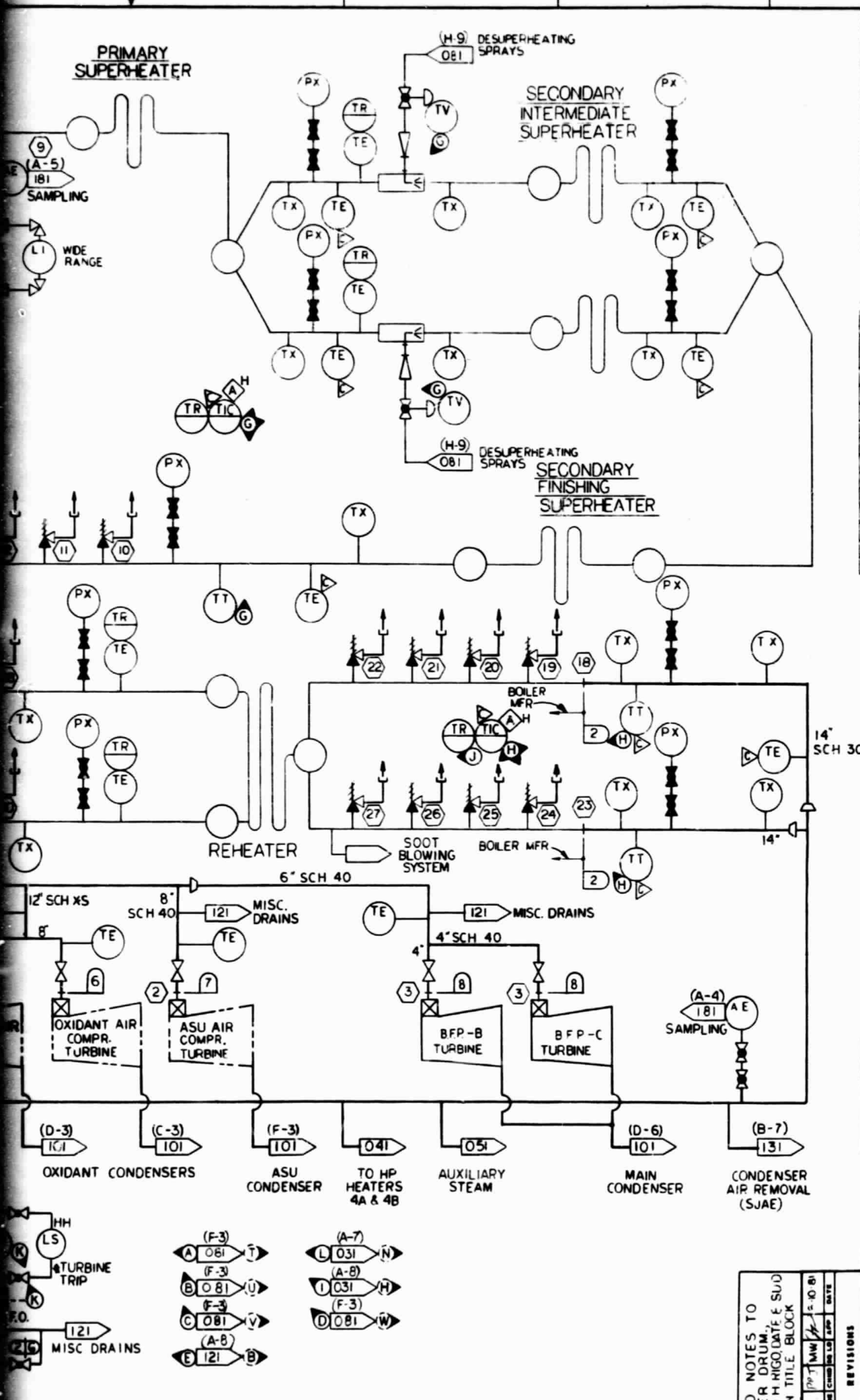
SUPERHEA
BOILER . DRUM
BA - I
NORMAL
HI LEVEL
WIDE RANGE
FROM DIFFUSER/ TRANSITION COOLING
081
FROM MHD POWER TRAIN
(A-5)
181
SAMPLING
WATER-WALL RECIRCULATION & DIFFUSER/TRANSITION COOLING
TO ATMOSPHERE
SILENCER
ELECTROMATIC RELIEF VALVE
BOILER MFR
(C-10)
031
TO H.P. BYPASS
10"ID
1.58 WALL
MISC DRAINS
121
(A-4)
181
SAMPLING
(A-3)
181
SAMPLING
7"ID
1.13" WALL
TO IP BYPASS
(D-6)
031
18" SCH 60
DRAIN TO CONDENSER
BOILER MFR
20" SCH.60
12" SCH.XS
14" SCH XS
MISC. DRAINS
121
12" SCH XS
8"SCH40
8"
TURBINE MFR
H.P TURBINE
I.P TURBINE
L.P TURBINE
OXIDANT AIR COMPR. TURBINE
(D-3)
101
OXIDANT CONDE
051
TO AUXILIARY STEAM
TO MAIN CONDENSER
101
14"
14" SCH 30
18" SCH,STD.
TURBINE TRIP
F.O.
121
MISC DRAINS
TURBINE TRIP SIGNALS FROM LOCATIONS NOTED ● - ALL DWGS.
CS
(D 8)
031
FROM H.P BYPASS
(G-5)
081
DESUPERHEATING SPRAY
FOLDOUT FRAME



OPERATING DATA

#	FLOW lb/HRx10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	535	1800	1000		HP TURBINE	
2	980	436	650		HP EXHAUST	
3	676	[illegible]	1000		IP TURBINE	
4	391	380	1000		DRIVE TURBINES	

DESIGN DATA

#	FLOW lb/HRx10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	1125	2070	1005		A335 GRADE P22	
2	562	2070	1005		A335 GRADE P22	
3	547	540	655		A106 GRADE C	
4	1,036	500	1005		A335 GRADE P22	
5	356	500	1005		A335 GRADE P22	
6	100	500	1005		A335 GRADE P22	
7	105	500	1005		A335 GRADE P22	
8	11	500	1005		A335 GRADE P22	

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I.D. NO. C-373-023

DATE	RELEASED FOR	ENGR.
3-27-81	CONCEPTUAL DESIGN ISSUE	
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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

MAIN & REHEAT STEAM SDD-011

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

SCALE NTS
8270-1-501-302-011 REV 1

REVISIONS: 1 — ADDED NOTES TO BOILER DRUM, ADDED H RIGO, DATE & SDD NO. IN TITLE BLOCK — 9-10-81

FOLDOUT FRAME 2

SYSTEM DESIGN DESCRIPTION

SDD-031

STEAM BYPASS AND STARTUP SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-504-302-031

Raimel Phim 3/11/81

SYSTEM ENGINEER DATE

Larry L. Wagner 3/17/81

Gary G. Hande 3/17/81

REVIEWED DATE

JW Phillips 3/18/81

APPROVED DATE

Revision: 1
Date: September 25, 1981
Approved: JW Phillips

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
STEAM BYPASS AND STARTUP SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Steam Bypass and Startup System as depicted on Fluid System Diagram 8270-1-504-302-031, Steam Bypass and Startup. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Steam Bypass and Startup System is designed to allow 50 percent of full load main steam to be bypassed to the main condenser. The system is designed to operate during any of the following plant conditions: cold start, warm start, hot restart, load rejection, quick shutdown of the turbine, and unit trip. This bypass capability minimizes turbine startup time and helps maintain MHD cycle and HR/SR boiler stability during transient operating conditions in the turbine cycle.

1.2 SYSTEM INFERFACES

Major equipment involved with the Steam Bypass and Startup System include the High Pressure (HP) and Intermediate Pressure (IP) Turbine, the Reheater, the desuperheaters and the Main Condenser. These components are described in the System Design Descriptions which interface with the Steam Bypass and Startup, namely Main and Reheat Steam, and Condensate. The Steam Bypass and Startup System also interfaces with the Heat Recovery/Seed Recovery (HR/SR) and Boiler Feedwater Systems.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure/temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures, temperatures, and "pipe sizing" flow rates are taken from the System Heat Balance Diagram and tabulated on the Fluid System Diagram 8270-1-504-302-031. Flow rates are those occurring during turbine valves wide open with the HR/SR steam outlet at maximum continuous rating conditions. Steam velocity is designed to be approximately 1,000 feet per minute per inch of internal pipe diameter.

2.0 DESIGN DESCRIPTION

The Steam Bypass and Startup System consists of piping, valves, desuperheaters, controls, and instrumentation. The major equipment components are covered in System Design Descriptions noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

The Steam Bypass and Startup System consists of two stages: the HP bypass stage which routes steam from the main steam header upstream of the HP turbine to the cold reheat header, and the IP bypass stage which routes steam from the hot reheat header upstream of the IP turbine to the main condenser.

Desuperheating water for the HP bypass stage is taken from the boiler feedwater pump discharge. The desuperheater line has a temperature control valve which regulates the flow to maintain the steam temperature approximately at cold reheat conditions. A pressure control valve is provided to ensure constant inlet pressure to the temperature control valve.

The IP bypass stage is similar to the HP bypass stage, except that a stop valve is provided downstream of the IP bypass pressure control valve. The stop valve is used to shut down the system during emergency conditions.

Attemperation of the IP bypass steam from the hot reheat is accomplished by feedwater taken from the same feedwater pump interstage bleed used for reheat desuperheating. The desuperheating water is injected into the IP bypass line downstream of the stop valve. Desuperheating water flow is controlled by a single flow control valve which is modulated to produce a flow that is adequate to maintain steam temperature at approximately 350°F.

Both HP and IP bypass stages are interlocked so that no steam can be bypassed if desuperheating spray water pressure is inadequate or flow is disrupted.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

With the exception of the equipment noted in Section 1.2, the Steam Bypass and Startup System consists of piping, valves, desuperheaters, and controls. The desuperheaters are of a standard manufactured design adequate for the service conditions.

HP Desuperheaters

Quantity	1
Type	Mfgr. Std.
Maximum Steam inlet flow	535,496 lb/hr
Maximum Steam inlet temp.	1005°F
Design Steam Pressure	500 psig
Steam Outlet temp.	450°F
Flow range	10-105%
Water Supply temp., max.	310°F
Water flow rate, max.	165 gpm

IP Desuperheaters

Quantity	1
Type	Mfgr. Std.
Maximum Steam inlet flow	610,904 lb/hr
Maximum Steam inlet temp.	1000°F
Design Steam Pressure	150 psig
Steam Outlet temp.	350°F
Flow range	10-105%
Water Supply temp., max.	215°F
Water flow rate, max.	417 gpm

2.2.2 Piping and Valves

The Steam Bypass and Startup System is designed with welded joints in accordance with ANSI B31.1. Piping materials are ASTM A 335 Grade P22 for all steam pipes and ASTM 106 Grade B for desuperheating water pipes. All piping is sloped downwards in the direction of flows to prevent water accumulation.

All valves are selected to be compatible with piping materials.

2.2.3 Electrical

The HP bypass desuperheating motor-operated valve is provided with 460 volt, 3 phase, 60 Hz power supplied from the 480 volt motor control centers.

2.2.4 Instruments, Controls, and Alarms

The Steam Bypass and Startup System is provided with appropriate instrumentation for sensing pressure, temperature and flow. Proper control and operation of the system is ensured by quick acting, positive response control valves and transmitters.

A pressure controller is provided for operating the HP bypass valve. This pressure controller receives a signal from a pressure transmitter on the main steam header. If the main steam header pressure exceeds the controller set point, the pressure controller opens the HP bypass valve.

A temperature transmitter is located in the HP bypass line downstream of the desuperheating injection valve. The temperature transmitter is interlocked with a temperature controller which activates the spray control valves and the desuperheating pressure control valve to open or close.

A pressure differential controller is provided to operate the IP bypass valve according to the pressure signals coming from the HP turbine inlet and the hot reheat.

A temperature controller located downstream from the IP desuperheater, regulates the water spray to limit the steam temperature to design conditions.

Flow transmitters are located in the IP steam line and the desuperheating water line. Both transmitters are interlocked with the pressure differential controller, to ensure that water flow is adequate for the steam being bypassed.

Temperature and pressure limit switches are installed in the IP bypass line to the condenser to alarm and shut down the system should abnormal temperature and pressure conditions develop. Also, pressure and temperature sensors on the condenser are interlocked with the controls for protection.

Both HP and IP bypass stages are provided with annunciating alarms in the main control room. The alarms are activated when steam temperature approaches a predetermined high high point.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The IP bypass stage has an extensive safety system designed to protect the main condenser from abnormal operating conditions. Should desuperheating water flow be inadequate, a flow transmitter (located across an orifice in the desuperheating line) will close the IP bypass pressure control valve. A second line of safety is provided by the bypass stop valve which is closed on high pressure by a vacuum switch in the condenser, or by the pressure and temperature switches located in the steam discharge line to the condenser.

To protect the HP turbine against steam from the cold reheat system during bypass operation, a check valve is installed in the reheat line near the turbine.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Steam Bypass and Startup System beyond those normally observed in conjunction with high temperature and high pressure piping.

3.3 PRECAUTIONS

There are no special precautions for safe operation of the Steam Bypass and Startup System. Startup, normal operation and shutdown must be in accordance with instructions received from the HR/SR, turbine, and condenser manufacturers.

4.0 MODES OF OPERATION

4.1 STARTUP

Startup of the Steam Bypass and Startup System can be initiated manually or automatically. Manual operation is required during a turbine or plant startup from any of the following conditions: cold startup, warm startup and hot restart. Automatic operation of the system is initiated when the main turbine trips or when there is a sudden load rejection which results in excess pressure buildup in the main steam system.

The automatic mode of the Steam Bypass and Startup System is controlled by the HR/SR superheater pressure controller, turbine throttle valve, and hot reheat pressure controller. An unbalance between the HR/SR steam output and the HP turbine inlet results in a main steam pressure increase. If this increase exceeds a preselected setpoint, (such as would occur on a turbine trip) the HP bypass valves open to admit steam to the cold reheat header. Steam flowing to the reheater, raises the hot reheater pressure. When the hot reheat pressure rises, the preselected pressure difference required between the HP turbine inlet and the hot reheat is not met, and the IP bypass controller will open the bypass valves to allow steam bypass to the main condenser. Flow is limited to approximately 50 percent of main steam flow by equipment and piping.

During the cold startup phase, (initial metal temperature of the HP turbine casing less than 300°F) the set-point pressure of the HP bypass pressure control is adjusted from the control room to match the live steam pressure. With steam flow established through the reheater, the turbine is gradually warmed up and brought up to synchronization speed. After final checks have been made, the turbine is synchronized and loaded, and the bypass system flow gradually reduced as load is increased. Amount of flow will be determined by the MHD power train requirements.

Warm startup is defined as when the metal temperature of the HP turbine casing is above 300°F. The procedure for the operation of the Steam Bypass and Startup System is the same as for cold startup. However, a faster startup time between the first turbine roll and full load is possible with warm startup.

Hot restart may be necessary if a minor failure tripped the unit. On a turbine trip, the throttle valve automatically closes, causing the pressure to build up in the HR/SR superheater outlet header. On rising pressure, the bypass valves open quickly and the desuperheating spray control valves will automatically regulate the transient steam temperature.

If the fault is remedied within a short time, the steam flow can be returned to the turbine quickly (Since the turbine metal temperature is still near to full load temperature) and turbine loading restored within the manufacturer's rate limits. Bypass flow is reduced as loading is increased.

4.2 NORMAL OPERATION

The Steam Bypass and Startup System is considered to be operating normally when it maintains bypassed steam conditions within a predetermined range.

Normal operation of the Steam Bypass and Startup System can be expected during cold startup, warm startup, and hot restart. Emergency plant conditions such as a unit trip, turbine trip or sudden rejection of load will initiate transient operating conditions which may cause the system to operate quickly and a momentary deviation from normal design conditions could occur until system stability is restored.

4.3 SHUTDOWN

The Steam Bypass System will shut down automatically when HR/SR main steam outlet conditions are restored to normal. The system can also be shutdown from the main control room by remote operation of the control valves.

4.4 SPECIAL OR INFREQUENT OPERATION

Normally, the Steam Bypass and Startup System is designed to handle 50 percent of the rated steam flow. This steam flow is sufficient to assure stable run up and loading characteristics and to allow load rejection without blowing the HR/SR safety valves.

Should a turbine generator trip occur, the Bypass System will not be able to accommodate all of the flow from the sudden load rejection and, consequently, the safety valves will blow to relieve the excess steam.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

An in-house computer system will monitor the steam temperature after steam leaves the HP and IP desuperheaters. This will alert plant operating personnel to any off-design performance or operation.

5.2 INSERVICE INSPECTION

All piping, valves, controls, gauges, pipe supports, etc., shall be visually inspected periodically during system operation to ensure that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Since the Steam Bypass and Startup System is mainly a piping and valve system, and is not expected to operate frequently, little maintenance is anticipated.

Other than an annual maintenance program, a frequent preventative maintenance program is not essential.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. Critical parts and parts requiring long lead (delivery) times will be kept in inventory at the plant.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
STEAM BYPASS AND STARTUP SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

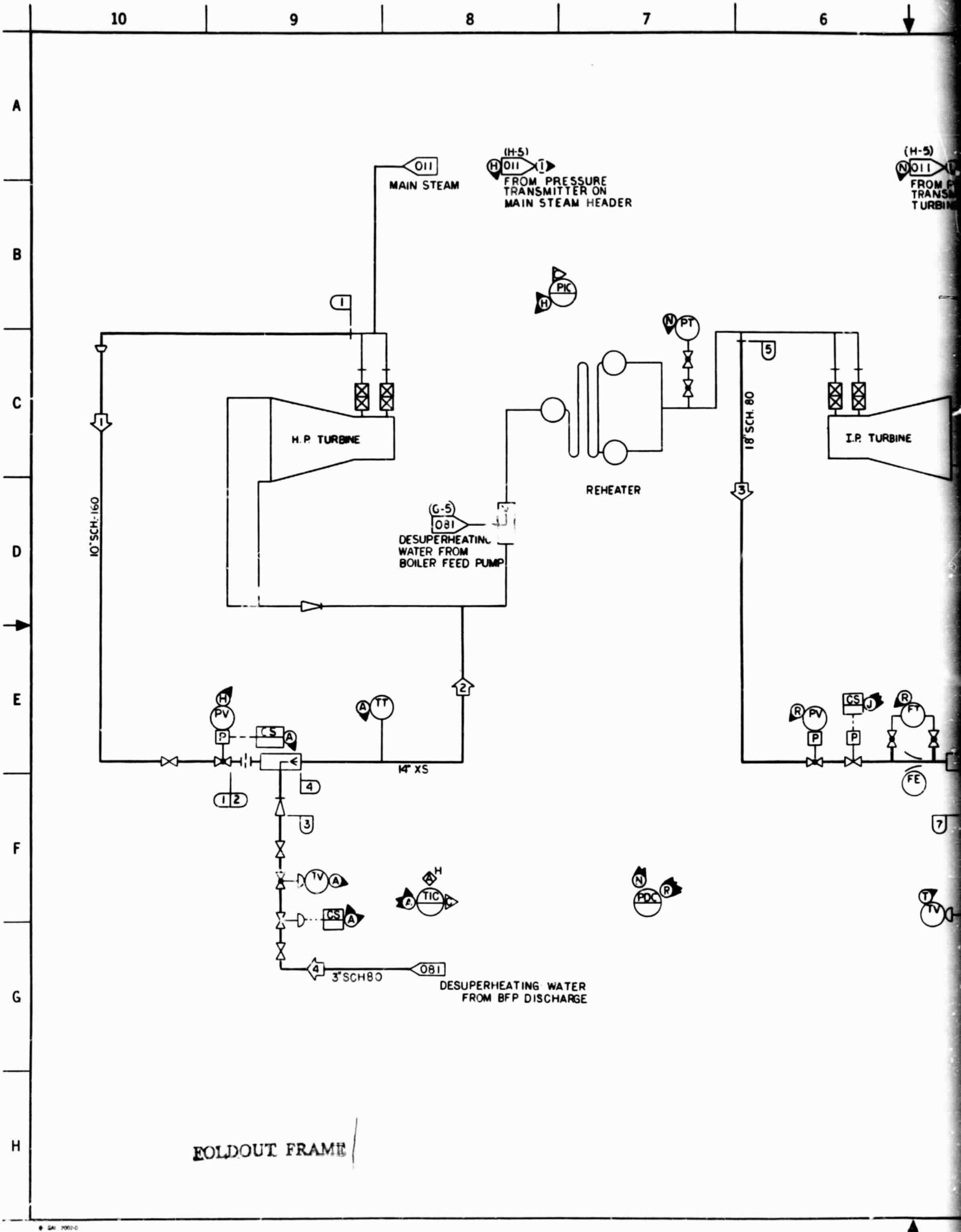
Fluid System Diagrams	Diagram No.
Steam Bypass and Startup	8270-1-504-302-031

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Main & Reheat Steam
Condensate

Plant Heat & Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001



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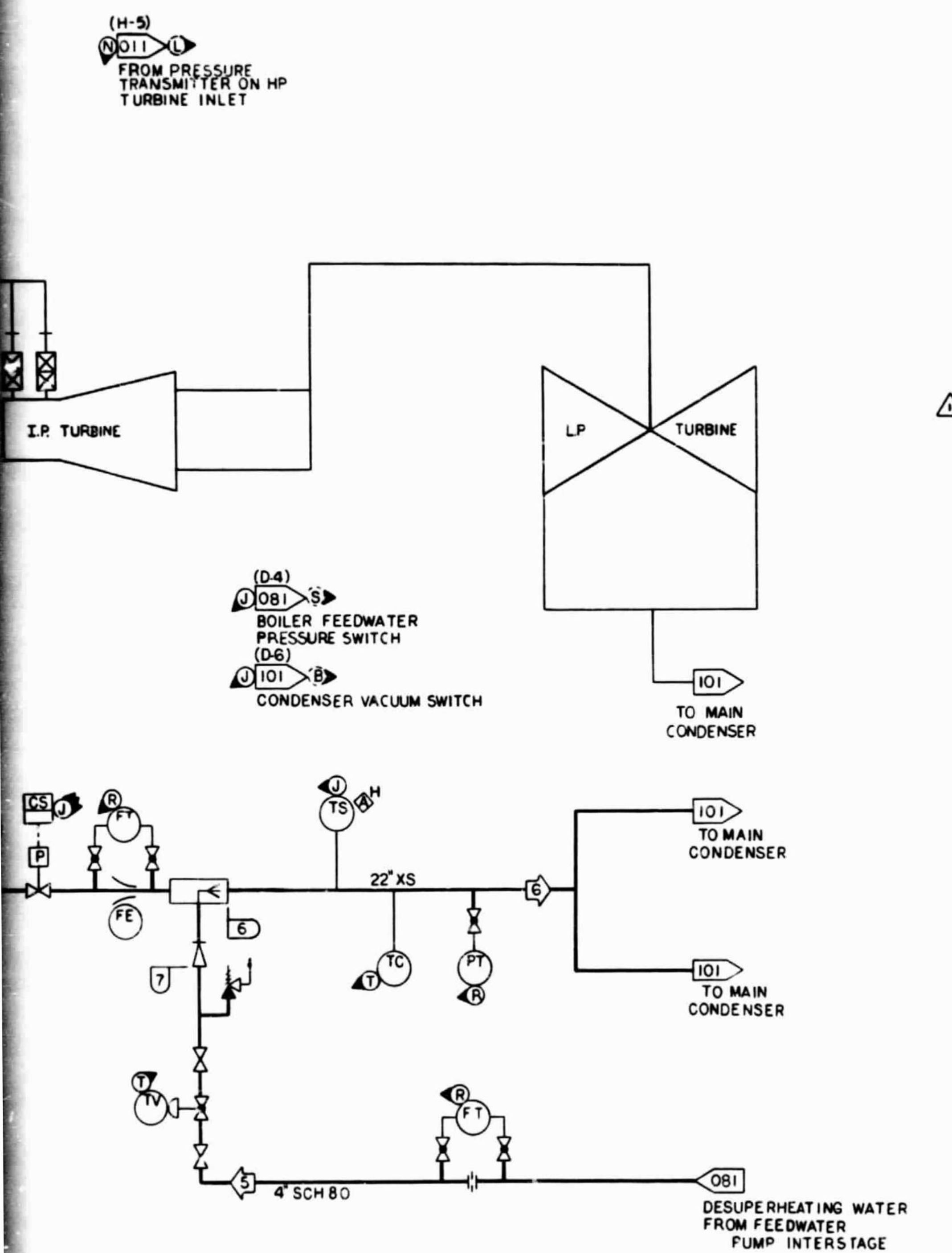

OPERATING DATA

#	FLOW LB/HR×10³	PRESS. PSIG	TEMP. °F	BY	REMARKS	REV.
1	535	1695	1001		MAIN STEAM BYPASS	
2	611	415	650		TO REHEATER	
3	611	415	1001		REHEATER OUTLET	
4	75	2254	307		F.W. DISCH. INJ.	
5	210	235	307		F.W. DISCH. INJ.	
6		150	345		TO CONDENSER	

DESIGN DATA

#	FLOW LB/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	560	2000	1010		ASTM A335 GR P22	
2	560	475	1010		ASTM A335 GR P22	
3	80	2400	320		ASTM A106 GR B	
4	640	475	655		ASTM A335 GR P22	
5	640	450	1005		ASTM A335 GR P22	
6	850	175	350		ASTM A335 GR P22	
7	220	275	320		ASTM A106 GR	

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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEMS DIAGRAM
STEAM BY-PASS AND START-UP — SDD-031
200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

SCALE NONE
8270-1-504-302-031
DRAWING NUMBER
088270-001

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FOLDOUT FRAME 2

SYSTEM DESIGN DESCRIPTION

SDD-041

EXTRACTION STEAM SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-503-302-041

R. B. Jensen — Feb 5, 1981

SYSTEM ENGINEER — DATE

T C Reitz — Feb 27, 1981

REVIEWED — DATE

APPROVED — DATE

Revision: 1
Date: September 25, 1981
Approved: [signature]

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
EXTRACTION STEAM SYSTEM

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Extraction Steam System as depicted on Fluid System Diagram 8270-1-503-302-041, Extraction Steam. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Extraction Steam System is designed to convey steam extracted from the main steam turbine to the regenerative feedwater heaters through piping and valves as follows:

From High Pressure (HP) Turbine exhaust to Heaters 4A and 4B,
From Intermediate Pressure (IP) Turbine to Heaters 3A and 3B,
From IP Turbine to Heaters 2A and 2B,
From Low Pressure (LP) Turbine to the Deaerating Heater (Heater 1).

1.2 SYSTEM INTERFACES

Major equipment components involved with the Extraction Steam System include the HP, IP, and LP turbines, regenerative feedwater heaters, and the deaerator and storage tank. These components are described in the System Design Descriptions which interface with Extraction Steam, namely Main and Reheat Steam, Boiler Feedwater, and Condensate. Extraction Steam also interfaces with other major systems such as Auxiliary Steam, Feedwater Heater and Miscellaneous Drains and Vents, and Feedwater Heater Drips.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)

7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures, and "pipe sizing" flow rates are taken from the plant heat and flow balance diagram and tabulated on the fluid system diagram 8270-1-503-302-041. Flow rates are those occurring during main steam turbine valves wide open with the Heat Recovery/Seed Recovery (HR/SR) steam outlet at maximum continuous rating conditions. Extraction pipe sizing is based on pressure drop, as a percent of normal (design) extraction pressure, and a steam velocity limited to 1,000 feet per minute per inch of internal diameter. Pressure drops are limited to a range of approximately 3 percent to 6 percent of the extraction pressure at the turbine nozzles.

2.0 DESIGN DESCRIPTION

The Extraction Steam System consists of piping, valves and controls. The major equipment components are covered in System Design Descriptions noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

Steam is extracted from the main steam turbine for regenerative feedwater heating. Four stages of extraction steam are provided.

The first extraction is from the Low Temperature or Cold Reheat System which comes from the exhaust of the HP turbine. This extraction provides steam to feedwater heaters 4A and 4B. The extraction pipe takeoff from the cold reheat header is a single line which divides into two branches to the inlets of heaters 4A and 4B.

The second extraction point is from the IP turbine, and it provides steam to feedwater heaters 3A and 3B. The extraction line from the IP turbine is a single pipe which divides into two branches to the inlets of heaters 3A and 3B.

The third extraction is also from the IP turbine and it provides steam to feedwater heaters 2A and 2B. This extraction line from the IP turbine is a single pipe which divides into two branches to the inlets of heaters 2A and 2B.

The fourth extraction is from the LP turbine and provides steam to the deaerator (heater number 1). The extraction steam comes from two equal points on the double-flow LP turbine which are joined together inside the main surface condenser as one pipe, passing through the condenser wall (with a bulkhead expansion joint) to the deaerator.

Turbine protection from overspeed on a turbine trip, caused by reverse flow of flash steam from the heaters through the extraction piping to the turbine, is

provided through the use of positive closing, balanced disc, non-return valves located in all extraction lines. The extraction non-return valves are located only in horizontal runs of piping and as close to the main steam turbine as possible.

Water is prevented from entering the turbine, while it is operating, through the use of motor-operated gate valves in each branch of the extraction piping. The motor-operated gate valves close automatically on high level signal from a level switch located on the heater being supplied with extraction steam. The high water level switch will also energize the solenoid of the air cylinder to close the non-return valve, and actuate an alarm in the control room. The motor-operated gate valve position limit switch opens the drain valves on the corresponding extraction steam drain manifold to the condenser.

Control switches, for remote-manual operation, are provided in the control room for each motor-operated gate valve. This remote-manual valve operation also de-energizes the solenoid on the air cylinder thus closing the non-return valve. The valves cannot be returned to their normal positions until the high water level switch indicates that the water level has fallen to its normal operating position.

A turbine trip signal also automatically closes the non-return valves through relay dumps. The remote-manual control for each heater level control system is used to release the non-return valves to normal check valve service when required to restart the system.

Drains are provided at low points on the turbine side of the motor-operated gate valves and the non-return valves. These drains include drain pots with level switches, automatic drain valves, and high level alarms.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment components shown on the Extraction Steam System diagram are the deaerator and storage tank, main steam turbine (HP, IP, and LP casings), and the feedwater heaters. These items are described in the following System Design Descriptions:

Item	System Design Description	Fluid System Diagram
Deaerator and Storage Tank	Condensate System	8270-1-511-302-101
Main Turbine	Main & Reheat Steam System	8270-1-501-302-011
Feedwater Heaters	Boiler Feedwater System	8270-1-521-302-081

2.2.2 Piping and Valves

The extraction non-return valves are free flowing, swinging disc, non-return valves with piston operators, which are activated by control signals as described in Section 2.1. These valves are designed in accordance with ANSI B16.34. The shaft-to-disc connections are designed in such a way that the valve will perform like an ordinary check valve when air is applied to the piston. Upon loss of air, spring action forces the disc toward the closed position.

Extraction Steam System valves are arranged for isolation of all feedwater heaters. These motor-operated gate valves are forged steel with butt-weld ends. Vent, drain, and instrument valves are forged steel, welded end globe valves designed in accordance with ANSI B16.34.

The extraction steam system piping is designed with welded joints in accordance with ANSI B31.1.

Piping materials are in accordance with the following:

Extraction	Material - ASTM No.
No. 4 Heaters - Cold Reheat	Carbon Steel - A106
No. 3 Heaters - IP Extraction	Chrome Moly Steel - A335
No. 2 Heaters - IP Extraction	Chrome Moly Steel - A335
No. 1 (Deaerator) - LP Extraction	Carbon Steel - A106

Valve body materials are compatible with pipe material.

2.2.3 Electrical

Motor-operated valves are 460 volt, 3 phase, 60 Hz, with power supplied from the 480 volt motor control centers. Solenoid valves will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls and Alarms

The Extraction Steam System is provided with appropriate instrumentation for sensing level, pressure, and temperature at points commensurate with good design practice to monitor system performance. Pressure and temperature sensors are located on the steam inlet to each feedwater heater and the signals transmitted to the control room computer. Controls for the various valves are described in Section 2.1.

The extraction non-return valves and the motor-operated valves described herein are interlocked with control signals and alarms which are described in the System Design Description for the Feedwater Heater Drips System and shown on Fluid System Diagram 8270-1-525-302-111.

The drain pot automatic drain valves are opened on a high level signal from the drain pot level switch. Level alarms (which annunciate in the main control room), are provided for each drain pot level switch described in Section 2.1.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits and protective devices will be described and included in System Design Descriptions noted in Section 1.2.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Extraction Steam System beyond those normally observed in conjunction with high temperature and high pressure piping.

3.3 PRECAUTIONS

The requirements and recommendations for the prevention of water induction into the steam turbines (ASME Standard No. TDP-1-1980) has been included in the system design and must be followed in the operation of the Extraction Steam System.

4.0 MODES OF OPERATION

4.1 STARTUP

Steam for deaeration may be provided initially from the Auxiliary Steam System which is replaced by steam from the main turbine extraction system when the unit is above approximately 50 percent load.

The Extraction Steam System and the associated feedwater heaters are prepared for operation by placing control switches for all stop, non-return, and level control valves in the "Normal" position. The drain valves in the Extraction Steam System must all be in the open position. The heater vents must be open to the condenser. As steam flow is increased in the main steam turbine, steam will begin to flow into the feedwater heaters. When the individual extraction lines are warmed and the drains are cleared, the drain valves and startup vents are closed. Drain pot automatic drain valves and heater level controls are returned to the automatic mode.

A hot startup condition occurs when there is residual heat in the entire power plant and the time frame is only limited by the rate at which the HR/SR can be heated and the main steam turbine can resume load. The starting procedures are the same as for an initial start except the piping and equipment can come up to operating temperature more quickly.

4.2 NORMAL OPERATION

The normal load range of the steam turbine generator, and consequently the Extraction Steam System, is categorized as base load with very little part

load operation below 75 percent total plant load. Should the unit be operated below this level, administrative action will verify that drain valves have opened automatically at 20 percent and lower load ratings.

The Extraction Steam System is capable of operating satisfactorily and with no special operator action in the event of load changes on the Unit.

4.3 SHUTDOWN

In a normal, controlled shutdown the steam line drain valves are opened at about 20 percent load on the steam turbine generator. No other operator action is required. On a steam turbine generator trip the stop and non-return valves will close automatically and the drain valves open automatically. Operator attention is required to confirm proper operation of these valves.

4.4 SPECIAL OR INFREQUENT OPERATION

The Extraction Steam System valves and controls are designed to prevent water induction and steam reverse flow from entering the main steam turbine following a turbine trip. A high feedwater level in a heater diverts incoming drains directly to the main condenser. A very high feedwater heater level closes the non-return valve(s) and the stop valve and opens the extraction piping drain valves. This effectively removes the heater from the system and prevents water induction into the main steam turbine. On a main steam turbine trip, extraction non-return and stop valves are closed to prevent steam from flowing back into the turbine which could cause overspeed.

A half string of 3 feedwater heaters can be isolated for inspection or service by bypassing the feedwater and closing the steam and water valves. To return the heaters to service the non-return valves are released and the line pressures balanced with the stop valves.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

An in-house computer system will monitor significant data points in the Extraction Steam System to parallel the automatic controls. This will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance shall be carried out on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

All piping, valves, controls, gauges, pipe supports, etc., shall be inspected periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., depending on the recommendations of the equipment manufacturer. In general, equipment parts will be replaced during planned shutdown if they are near the end of their recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT

SYSTEM DESIGN DESCRIPTION

EXTRACTION STEAM SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Extraction Steam	8270-1-503-302-041

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions

Main & Reheat Steam

Auxiliary Steam

Boiler Feedwater

Condensate

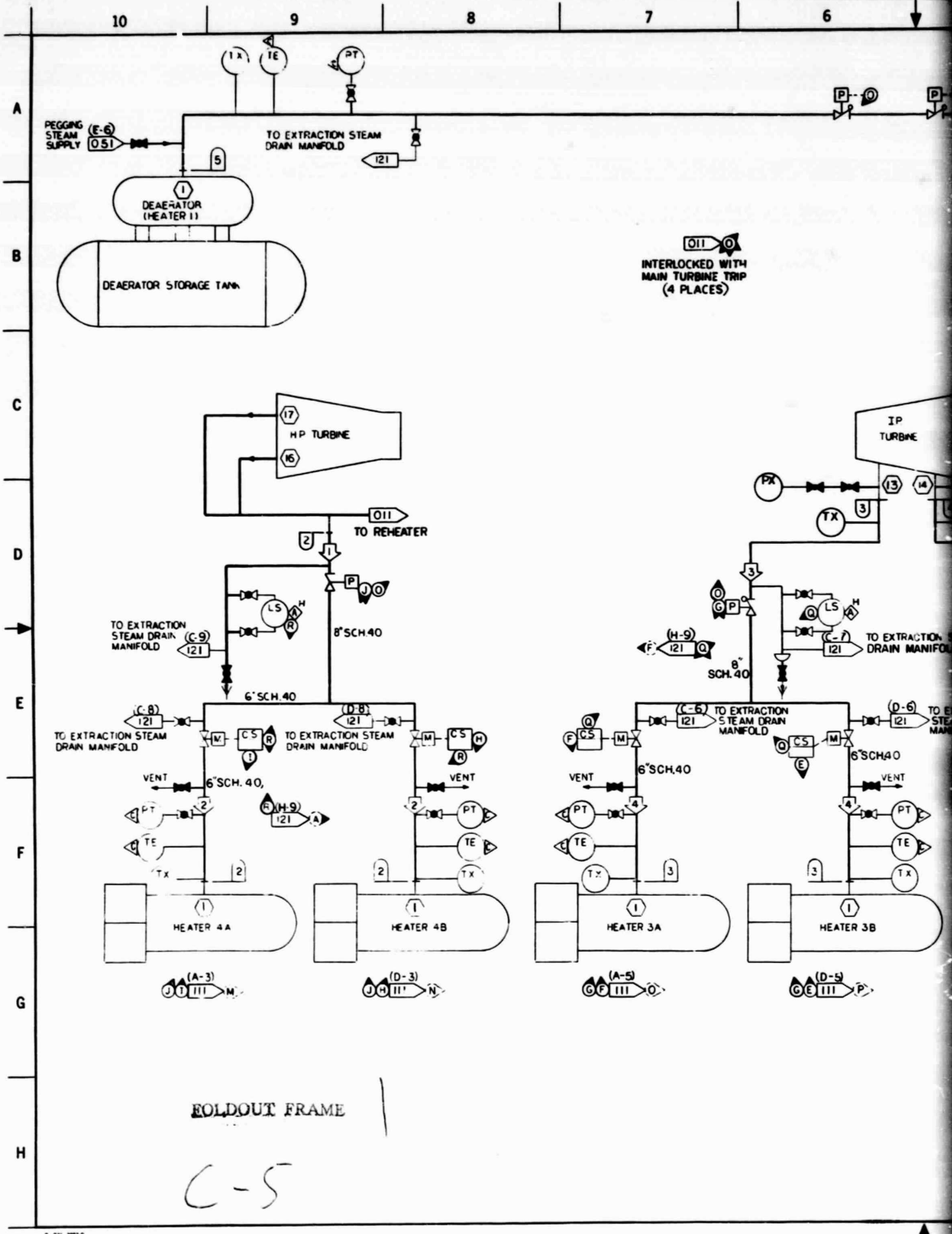
Feedwater Heater Drips

Feedwater Heater and Miscellaneous Drains & Vents

Plant Heat & Flow Balance Diagram

System Heat Balance 8270-1-540-314-001

ASME Standard No. TDP-1-1980 "Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation"; Part 1 - Fossil Fueled Plants



FOLDOUT FRAME

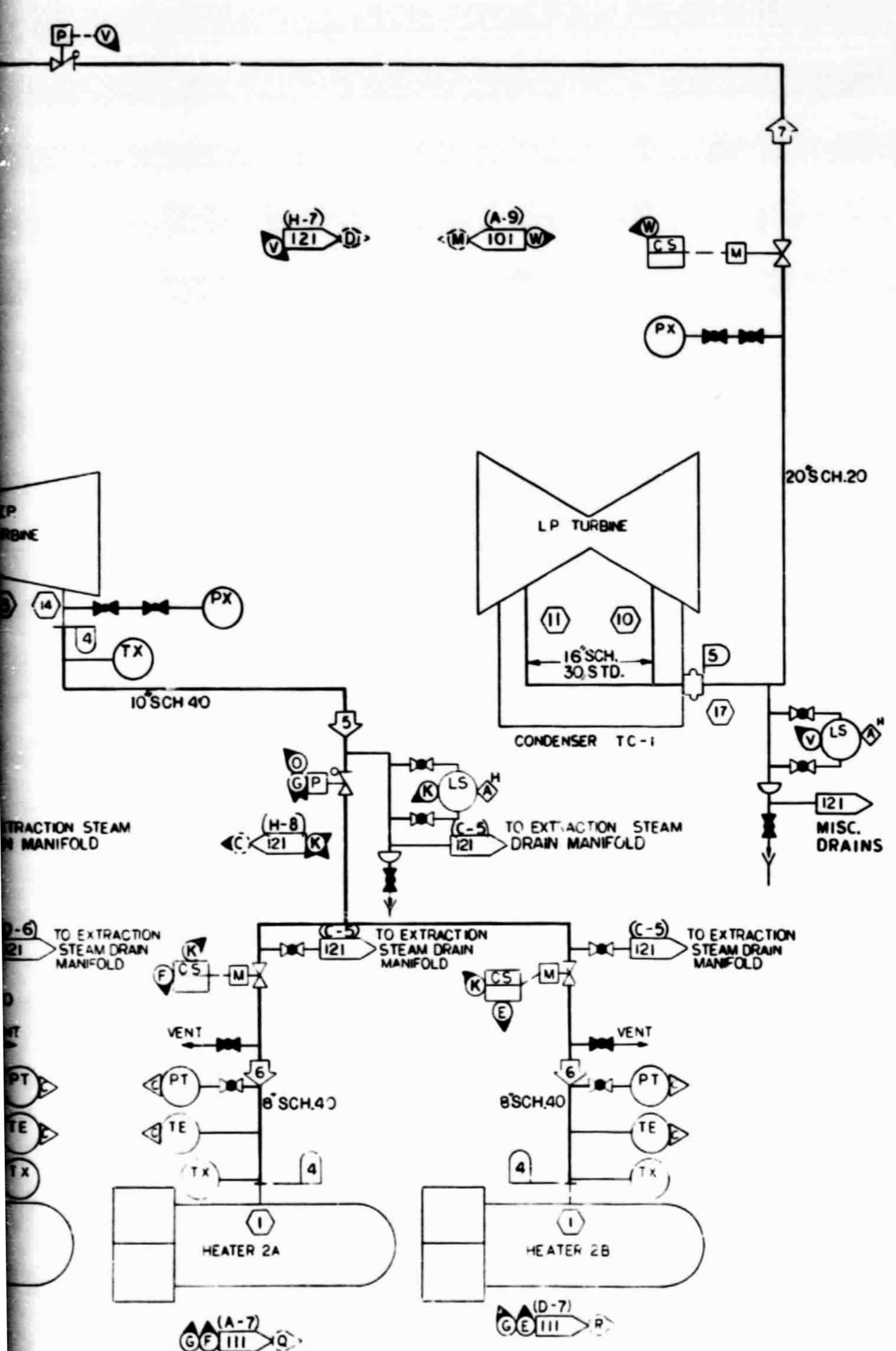
C-5

OPERATING DATA

FLOW lb/hr×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1 54.3	436	650		COLD RH.	
2 27.1	423	650		HTRS.4A & 4B	
3 38.4	277	918		I.P. EXTR. PT.	
4 19.2	260	918		HTRS. 3A & 3B	
5 51.8	166	798		I.P. EXTR. PT.	
6 25.9	155	798		HTRS. 2A & 2B	
7 68.1	1	308		L.P. EXTR. PT.	

DESIGN DATA

	FLOW lb/hr×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1						
2	57.0	475	655		A106, GRADE B	
	28.5	475	655		A106, GR.B	
3	40.4	300	923		A335, GR.P22	
	20.2	300	923		A335, GR.P22	
4	54.4	175	803		A335, GR.P22	
	27.2	175	803		A335, GR.P22	
5	71.5	50	313		A106, GR.B	
	35.8	50	313		A106, GR.B	



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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

EXTRACTION STEAM SDD-041

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

REVISIONS: 1 ADDED H. RIGO, DATE & SDD NO. IN TITLE BLOCK

SCALE NTS
8270-1-503-302-041 REV 1
DRAWING NUMBER

SYSTEM DESIGN DESCRIPTION

SDD-051

AUXILIARY STEAM SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-507-302-051

SYSTEM ENGINEER DATE

LWagner 3-6-81

3-6-81

REVIEWED DATE

3/10/81

APPROVED DATE

Revision: 1
Date: September 25, 1981
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MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
AUXILIARY STEAM SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Auxiliary Steam System as depicted on Fluid System Diagram 8270-1-507-302-051, Auxiliary Steam. The document includes descriptions of system functions, interfaces with other systems, equipment piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Auxiliary Steam System is designed to provide two levels of low pressure steam (100 psig, 350°F and 40 psig, 300°F to 500°F), primarily for assisting cold startup of the plant. This steam will be conveyed from the auxiliary boilers or from the main cycle through piping and valving to the following end points for utilization:

1. Building Heating Steam
2. Flue Gas Sampling
3. Steam Coil Air Preheater
4. Vitiated Air Preheater
5. Boiler Feedwater Pump Turbines
6. Main Deaerator and Storage Tank
7. Auxiliary Deaerator Sparging System
8. Condensate Demineralizers
9. Steam Coil Supply
10. Auxiliary Boiler Deaerator Steam Supply
11. Main Turbine Gland Seal Steam
12. Main Turbine Warm-up Steam
13. ASU Compressor Turbine and Vaporizer
14. Oxidant Compressor Turbines

Steam supply will be from two light oil fired boilers each capable of 135,000 lb/hr maximum continuous rating at 100 psig, 350°F.

1.2 SYSTEM INTERFACES

Major plant equipment components which interface with the Auxiliary Steam System include the High Pressure (HP), Intermediate Pressure (IP), and the Low Pressure (LP) turbines, and the main cycle deaerator and storage tank. These components are described in the System Design Descriptions which interface with Auxiliary Steam, namely Main and Reheat Steam, and Condensate. Auxiliary Steam also interfaces with other systems such as Feedwater Heaters, Miscellaneous Drains, Vents and Reliefs, Plant Makeup Water, HVAC, and Boiler Flue Gas.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components. Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations.

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures, temperatures, and pipe sizing flow rates are taken from the design requirements for the various auxiliary steam uses. The steam load requirements during startup are:

		Normal lb/hr x 1000
1.	Building Heating Steam	31.0
2.	Flue Gas Sampling	0.1
3.	Steam Coil Air Preheater	22.6
4.	Vitiated Air Preheater	0.2
5.	ASU Turbine Seals, Warming	5.0
6.	Main Deaerator and Storage Tank	30.0
7.	Auxiliary Deaerator Sparging	8.0
8.	Condensate Demineralizers	3.0
9.	Steam Coil supply	10.0
10.	Auxiliary Boiler Deaerator steam supply	10.0
11.	Main Turbine Gland Seal Steam	10.0
12.	Main Turbine Warming Steam	10.0
13.	ASU Services, Oxygen Vaporizer	20.0

Auxiliary Steam System pipe sizing is based on pressure drop, as a percent of normal (design) pressure and/or steam velocity which is limited to 1,000 feet per minute per inch of internal diameter. Condensate return piping has a water velocity limitation of 10 ft/sec.

2.0 DESIGN DESCRIPTION

The Auxiliary Steam System consists of the auxiliary boilers, auxiliary boiler deaerator and storage tank, auxiliary boiler feedwater pumps, piping, valves, and controls. Other equipment components which interface with Auxiliary Steam are covered in the System Design Descriptions noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

The Auxiliary Steam System will provide low pressure steam from two oil fired auxiliary boilers. This steam will be used by the station services noted in Section 1.1. The Auxiliary Steam System is provided with steam tie-ins from the cold reheat manifold (HP turbine exhaust) and the low pressure crossover (IP turbine exhaust) so that main cycle steam may be used.

Primary level (100 psig, 350°F) steam is made available for use at the vitiated air heater, auxiliary deaerator steam inlet, steam coil, auxiliary sparger, main and ASU turbine seals, and main turbine during warmup.

The primary level steam supply has a tie-in from the cold reheat manifold for use during normal operation.

A secondary level (40 psig, 300°F) steam pressure is made available for building heating, flue gas sampling, steam air preheating, fuel oil heating, and condensate demineralizer (caustic heating) through the use of a pressure reducing station from the primary level steam supply. The secondary level header is provided with a connection from the low pressure crossover line. Thus, the secondary level steam header has the capability of being supplied by the auxiliary boilers, cold reheat or low pressure crossover steam.

Steam air preheater condensate, miscellaneous condensate returns, and building heating condensate are returned to the auxiliary deaerator via a common header for deaeration and temporary storage before recirculation to the auxiliary boilers.

A steam coil is installed in the lower drum of each auxiliary boiler to keep the boiler warm and ready for operation when it is not in service.

Steam for each steam coil supply is routed through a motor-operated gate valve and pressure reducing station. The steam coil condensate is returned through piping and valving to the auxiliary deaerator. A control switch, for remote-manual operation, is provided on the auxiliary boiler main control panel for the motor operated gate valve.

The auxiliary deaerator steam and the storage tank sparging steam are supplied through a normally open motor-operated gate valve. A control signal for the gate valve is received from a pressure transmitter on the Auxiliary Steam Supply System header. A self-actuated pressure regulating valve controls pressure level to the deaerator.

The auxiliary boilers are supplied with feedwater from the auxiliary deareator storage tank via a common header which is fed by two of three 100 percent capacity feedwater pumps (one for each boiler). The third feedwater pump will be maintained in a standby condition for emergency use. During normal operation of the auxiliary boiler the discharge flow of each feedwater pump is regulated between the recirculating line and the feedwater header. The recirculating flow control valves are actuated by pressure switches in the feedwater pump discharges. The auxiliary boiler feedwater flow control valve is actuated by a three element level control system on each auxiliary boiler.

Demineralized makeup water is introduced into the auxiliary deaerator from the plant Makeup Water System through a level control valve which is activated by the level switches on the deaerator storage tank.

Excess deaerator storage is relieved to the main condenser through a level control valve which is actuated by the level switches on the deaerator storage tank.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment components which interface with and are shown on the Auxiliary Steam System diagram are the main deaerator and storage tank, main turbine H.P., I.P., and L.P. casings, air preheater, and heating system equipment. These items are described in the following system design descriptions:

Item	System Design Description	Fluid System Diagram
Deaerator and Storage Tank	Condensate	8270-1-511-302-011
Main Turbine, ASU Turbine	Main & Reheat Steam	8270-1-501-302-011
Plant Heating Equipment	HVAC	8270-1-722-902-001
Air Preheater	Boiler Flue Gas	8270-1-403-302-322

Major equipment components shown on the Auxiliary Steam System diagram are:

1. Auxiliary Boilers

Quantity	2
Type	Natural circulation
Fuel	Light Oil (No. 2)
Steam Capacity (MCR)	100,000 lb/hr.
Steam Pressure	100 psig
Steam Temperature	350°F

2. Auxiliary Deaerator and Storage Tank

Deaeration	0.05 cc/1 Oz
Deaerator Type	Spray/tray
Inlet condensate flow, max.	220,000 lb/hr.
Steam Conditions	15 psig/320°F
Storage Tank	Horizontal
Tank Capacity	3,000 gallons

3. **Auxiliary Boiler Feedwater Pumps**

Quantity	**3 (100% each)**
Capacity	**200 gpm**
Total Head	**350 feet**
Motor HP	**30**
Motor speed	**3,600 rpm**

2.2.2 Piping and Valves

2.2.2.1 Piping

Piping used throughout the system is seamless carbon steel piping ASTM A106 Gr B. Piping is in accordance with ANSI B31.1. Piping low points are provided with drains and/or steam traps to remove any condensate.

2.2.2.2 Valves

Valves are carbon steel or alloy steel as required to conform to the piping in which they are installed. Vent, drum, and instrument valves are forged steel, weld end globe valves designed in accordance with ANSI B16.34.

2.2.3 Electrical

Pump motors and motor-operated valves are 460 volt, 3 phase, 60 Hz, with power supplied from the 480 volt motor control centers. Solenoid valves will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls, and Alarms

The auxiliary steam system is provided with appropriate instrumentation for sensing flow, pressure and temperature at points commensurate with good design practice.

Instrumentation typically found on package boilers includes a flow element to measure steam flow from the boiler, a drum level transmitter, feedwater flow transmitter, steam temperature, fuel oil supply pressure, air flow transmitter, drum pressure indicator and steam temperature transmitter.

Control for the various valves is provided by the instrumentation described in Section 2.1.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits and protective devices are described and included in System Design Descriptions noted in Section 1.2.

The piping and valve design limits are generally equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required, other than those indicated on Fluid System Diagram 8270-1-507-302-051.

Relief valves are provided on the auxiliary boiler, auxiliary boiler deaerator, and the tie-ins from the cold reheat and crossover steam lines for protection against steam over-pressure.

The deaerator storage tank is protected against high level by a level switch which actuates a dump valve to the main condenser.

The auxiliary boiler feedwater pumps are protected against debris damage by strainers in the suction intake line of each pump. The pumps are also protected against loss of flow by a low level switch on the deaerator storage tank and the minimum flow recirculating line.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Auxiliary Steam System beyond those normally observed in conjunction with high temperature and high pressure piping.

4.0 MODES OF OPERATION

4.1 STARTUP

For cold startup, the auxiliary feedwater cycle and boiler are filled from the auxiliary deaerator storage tank; the deaerator is at atmospheric pressure; the steam coil supply valve is open; the auxiliary deaerator steam inlet valve is closed and the main cycle tie-ins are isolated by the check valves.

When the boilers are fired a minimum design flow must be maintained through each furnace circuit. This minimum design is maintained through the use of the steam coil supply until saturated steam is available for admission to the deaerator steam inlet. The flow through the steam coil accelerates the temperature rise in the boiler and the temperature stability.

Once saturated steam is available the steam coil supply line is isolated and steam flow is directed to the deaerator steam inlet. At this time steam from the Auxiliary Steam System supply is available for use in assisting cold startup of the plant.

4.2 NORMAL OPERATION

During normal operation two levels (100 psig, & 40 psig) of low pressure steam are available for use throughout the plant. The primary level, 100 psig steam pressure, is obtained from either the auxiliary boilers or from the cold reheat supply from the H.P. turbine exhaust piping. The cold reheat supply automatically takes over supply from any other auxiliary steam source when cold reheat steam pressure is at or above 100 psig.

The secondary level, 40 psig steam pressure, is obtained from the auxiliary boilers, the cold reheat tie-in or from the crossover supply from the I.P. to L.P. turbines. The crossover supply takes over automatically when the crossover supply pressure is at or above 40 psig.

Whenever the cold reheat supply has been activated, the auxiliary boilers are placed in a standby condition. For high heating system demands at least one auxiliary boiler will be required to supplement cold reheat supply.

4.3 SHUTDOWN

Shutdown of an auxiliary steam boiler will commence when the cold reheat steam source begins supplying auxiliary steam. Ultimately the auxiliary boiler firing must be stopped and the auxiliary feedwater pumps shut off.

The auxiliary boilers may also be shutdown manually.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

The Auxiliary Steam System will be provided with sufficient automatic controls to ensure normal startup operation for the overall plant.

Initial firing and startup of the auxiliary steam system, however, will be performed manually by plant personnel as will be most shutdown operations.

Automatic controls have alert signals in the auxiliary boiler control area to warn of any off-design performance. Periodic testing of all reliefs and controls should be accomplished to verify proper operation.

5.2 INSERVICE INSPECTION

All piping, valves, controls, gauges, pipe supports, etc., shall be inspected periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., depending on the recommendations of the equipment manufacturer. In general, the part will be replaced during planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT

SYSTEM DESIGN DESCRIPTION

AUXILIARY STEAM SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

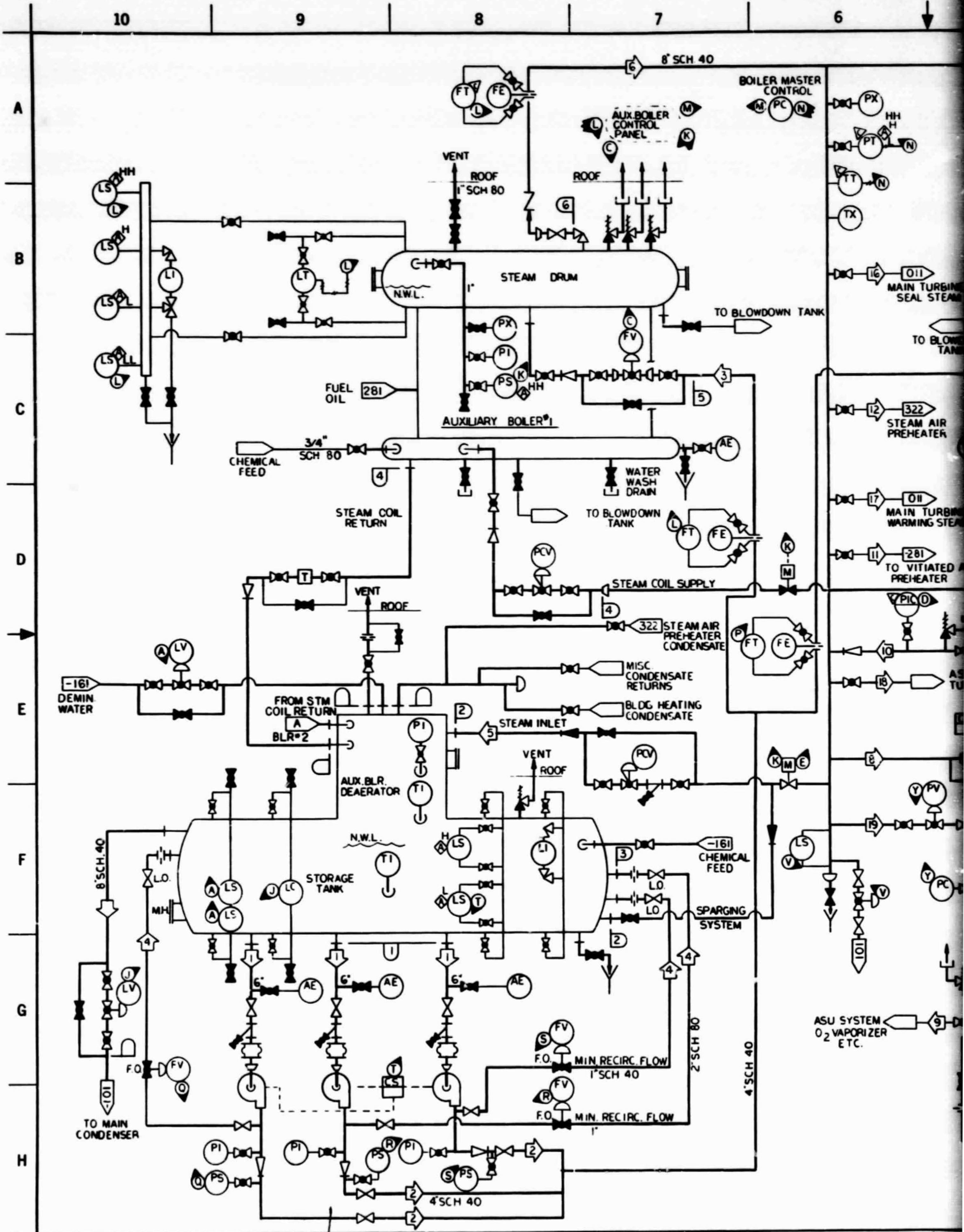
REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Auxiliary Steam	8270-1-507-302-051

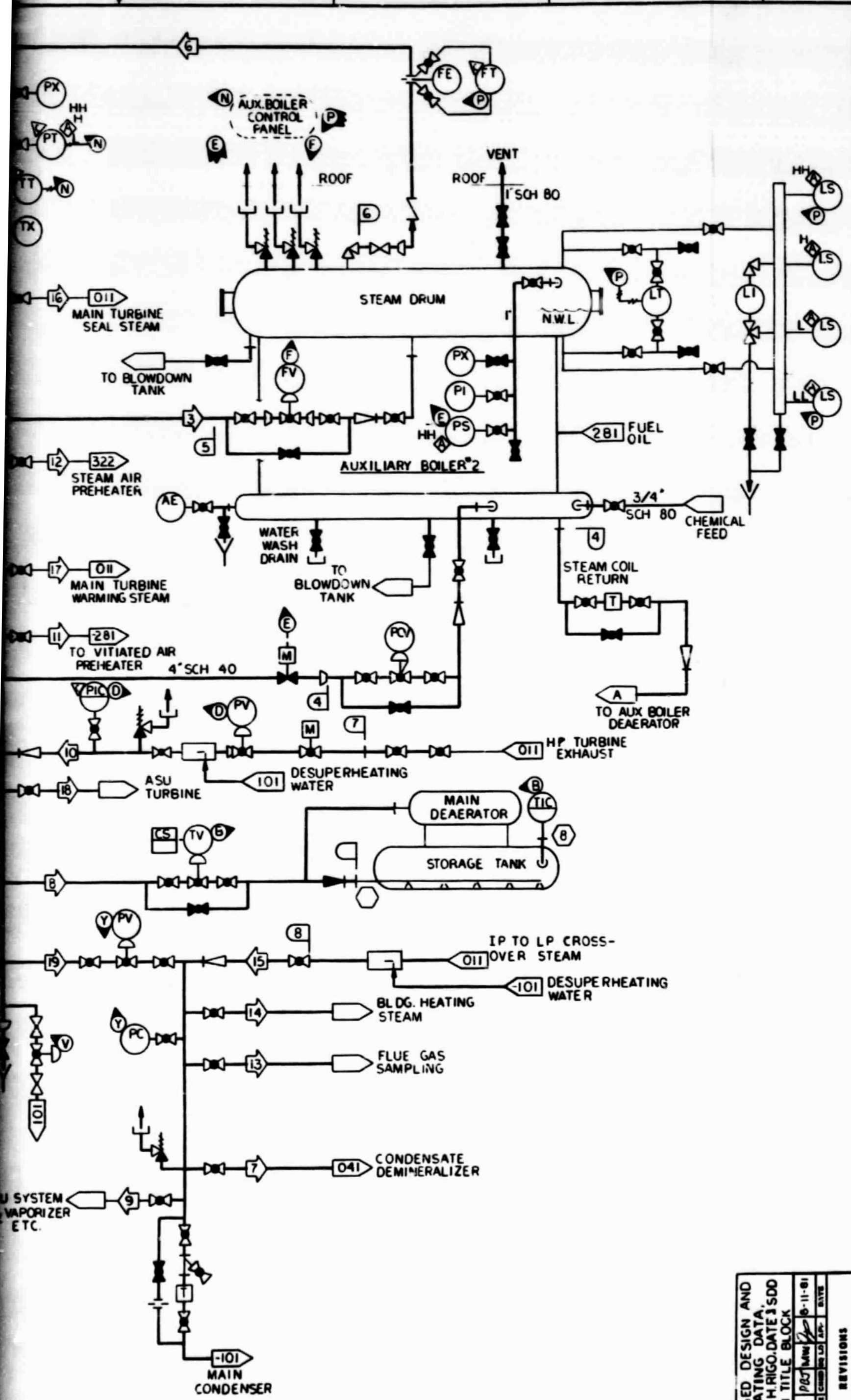
REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

- Main & Reheat Steam
- Plant Makeup Water
- Condensate
- Feedwater Heater Drips
- Miscellaneous Drains
- Oxidant Supply



FOLDOUT FRAME



OPERATING DATA

	FLOW LB/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	100	0.3	213		F.W. PUMP SUCT.	
2	100	135.0	213		F.W. PUMP DISCH.	
3	100	130.0	213		F.W. TO AUX. BLR.	
4	6.8	0.3	213		MIN. RECIRC. FLOW	
5	10.0	0.3	313		STEAM TO DA.	
6	100	100.0	350		AUX STEAM	
7	3	40.0	300		TO COND. DEMIN.	
8	30.0	100.0	350		TO MAIN DA.	
9	5.0	40.0	300		TO ASU O_2 VAP	
10	200.0	438.4	649.3		FROM MAIN TURB.	
11	0.2	100.0	350		TO VITIATOR	
12	22.6	100.0	350		TO STEAM PREHTR.	
13	0.1	40.0	300		TO FLUE GAS SAMP.	
14	31.0	40.0	300		FOR BLDG. HTG.	
15	125.0	40.0	300		FROM MAIN TURB.	
16	10.0	100.0	350		TO M.T. SEALS	
17	10.0	100.0	350		TO M.T. WARMING	
18	20.0	100.0	350		TO ASU TURBINE	
19		40.0	300			

DESIGN DATA

	FLOW LB/HR×10³	PRESS PSIG	TEMP F	BY	REMARKS	REV.
1	100.0	50	250		A106 GR.C	
2	10.0	50	400		A335 GR.P22	
3	6.8	50	250		A106 GR.C	
4	10.0	100	400		A106 GR.C	
5	100.0	150.0	250		A106 GR.C	
6	100.0	100.0	350		A335 GR.P22	
7	200.0	500.0	700		A355 GR.P22	
8	128.0	50.0	300		A106 GR.C.	

I.D. NO. C-373-024

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3-27-81	CONCEPTUAL DESIGN ISSUE	
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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

AUXILIARY STEAM SDD-051

200 MWe

DOE - NASA

MHD PROJECT OFFICE — APPV. H. RIGO

LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135 — DATE 9-25-81

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA

ENGINEERING INTERFACES

SCALE NONE — 8270-1-507-302-051 — REV 1

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REVISIONS: 1 | NL | PBJ | 6-11-81 | CHANGED DESIGN AND OPERATING DATA. ADDED H.RIGO. DATE & SDD NO. IN TITLE BLOCK

FOLDOUT FRAME 2

SYSTEM DESIGN DESCRIPTION

SDD-081

BOILER FEEDWATER SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-521-302-081

SYSTEM ENGINEER **DATE**

TC Reitz Feb 27, 1981

REVIEWED **DATE**

APPROVED **DATE**

Revision: 1
Date: September 25, 1981
Approved: [signature]

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
BOILER FEEDWATER SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Boiler Feedwater System as depicted on Fluid System Diagram 8270-1-521-302-081, Boiler Feedwater. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Boiler Feedwater System is designed to supply heated water to the Heat Recovery/Seed Recovery (HR/SR) Radiant Boiler for the generation of steam. In addition to this requirement, the system provides cooling for the MHD power train channel and combustor.

The Boiler Feedwater System is designed to meet the flow, pressure, and temperature requirements at all expected conditions and to provide stable operation during the most severe transient conditions. The system is also capable of responding to small stepload (N10 percent) or ramp changes without significant deviation from normal operation.

1.2 SYSTEM INTERFACES

Major equipment involved with the Boiler Feedwater System include two 100 percent boiler feedwater booster pumps, three 50 percent boiler feedwater pumps, six 50 percent closed feedwater heaters, high and low temperature economizers, MHD channel, combustor, nozzle, diffuser and transition section.

The Boiler Feedwater System interfaces with other major systems such as Extraction Steam, Main and Reheat Steam, and Condensate. The system also interfaces indirectly with systems such as Feedwater Heater and Miscellaneous Drains, Sampling, and Steam Bypass and Startup.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure/temperature ratings, and system limits to be used in the selection of the required components. Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
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3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)

6. Pipe Fabricators Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures, and "pipe sizing" flow rates are taken from the unit system heat balance diagram and tabulated on the Fluid System Diagram 8270-1-521-302-081. Flow rates are those occurring during main steam turbine valves wide open with the HR/SR steam outlet at maximum continuous rating conditions. Flow velocities for line sizing are generally limited to 15 feet per second. The velocity entering the feedwater heaters is limited to 10 feet per second. The maximum heater tubeside pressure drop, including inlet and outlet losses, is limited to 15 psi.

2.0 DESIGN DESCRIPTION

The Boiler Feedwater System provides the flow path for feedwater from the deaerator storage tank to the radiant boiler. Two 100 percent capacity motor-driven booster pumps take suction from the deaerator storage tank through individual lines and discharge through the MHD channel cooling system and the low temperature (LT) economizer to the suction header of the main boiler feed pumps. Three 50 percent boiler feedwater pumps are available for the final pumping of the feedwater through three stages of closed feedwater heating, the high temperature (HT) economizer and the MHD Power Train (combustor, nozzle, diffuser, and transition section) before entering the radiant boiler of the HR/SR.

2.1 SUMMARY DESCRIPTION

Feedwater from the deaerator storage tank is pumped by one of the two 100 percent capacity motor-driven booster pumps (one on standby). The suction line for each booster pump is piped directly from the deaerator storage tank, and includes a motor-operated isolation gate valve and a single basket strainer.

The booster pumps are located on the basement floor, 35 feet below the deaerator. The discharge line from each pump contains a check valve, motor-operated isolation valve, orifice flow meter and a branch recirculation line back to the deaerator storage tank. A common header distributes the feedwater to the MHD channel cooling circuit and the LT economizer. Both the MHD channel and the LT economizer have bypass capability for use during cycle cleaning and startup operation. From the LT economizer the feedwater is piped to the suction header of the boiler feedwater pumps.

Three 50 percent capacity boiler feedwater pumps (two turbine-driven and one variable speed motor-driven) are installed to provide final pumping of feedwater to the HR/SR Radiant Boiler. The suction pipe for each pump contains a motor-operated isolation gate valve, a single basket strainer and an orifice flow element. Each discharge line has a balanced-type, tilting disc check valve; a motor-operated, wye-pattern stop-check valve; and a branch recirculation line back to the deaerator storage tank.

The boiler feedwater pumps and drivers utilize a common, self-contained, lubrication system. Lubrication supervisory instruments are grouped on a single panel which is mounted on an adjacent column to minimize vibration.

The boiler feedwater pumps discharge the feedwater into a common header which distributes the flow through two parallel 50 percent capacity heater strings. Extraction steam from the HP and IP turbines is used as the heat exchange source to the heaters. Each heater string has three closed heaters arranged in series, and is provided with an upstream and downstream motor-operated isolation valve. A 50 percent capacity bypass line common to both strings of heaters is provided.

Feedwater flow to the HR/SR Radiant Boiler is measured using a flow nozzle element located downstream of the last heater. Before entering the HR/SR Radiant Boiler, the liquid enthalpy of the feedwater is further increased by flowing through the HT economizer, and the MHD Power Train. The HT economizer has bypass capability for cleaning, startup, or maintenance purposes. A recirculation line is provided on the discharge from the MHD Power Train which is used to maintain constant flow through the MHD circuit.

Boiler feedwater purity is automatically monitored and samples analyzed frequently to ensure that the quality is kept within the required range.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Operating data indicated are taken from or calculated from data shown on the System Heat Balance.

2.2.1.1 Boiler Feedwater Booster Pumps

Quantity	2
Type	Horizontal centrifugal
Capacity	2,500 gpm
Total Developed Head	600 ft.
Suction Pressure	70 ft.
Suction Temperature	225°F
NPSH Available	30 ft.
Efficiency (assumed)	70%
Brake Horsepower	517 hp
Pump Speed	3,600 rpm
Casing Material	Carbon steel
Shaft/Impeller Material	Stainless steel
Minimum Flow (Assumed @ 20%)	494 gpm
Motor Horsepower	600 hp

2.2.1.2 Main Feedwater Pumps

Quantity	3
Type	Horizontal, multi-stage,
centrifugal	

Capacity	**1,250 gpm**
Total Developed Head, across pump	**5,600 ft.**
Suction Pressure	**185 psig**
Discharge Pressure	**2,375 psig**
Suction Temperature	**310°F**
Efficiency (assumed)	**75%**
Brake Horsepower	**2,250 hp**
Pump Speed	**(TBD) rpm**
Casing Material	**Carbon steel**
Shaft/Impeller Material	**Stainless steel**
Minimum Flow (assumed @ 30%)	**369 gpm**
Interstage Bleed (Attemperation)	**100 gpm @ 550 psig**

2.2.1.3 Feedwater Pump Turbine Drives

Quantity	2
Type	Multi-stage, condensing
Power Output	2,300 hp
Speed	(TBD) rpm
Steam Inlet Pressure	380 psig
Steam Inlet Temperature	1000°F
Exhaust Pressure	2.5 in. Hg. Abs.
Control System	Electro-hydraulic
Casing Material	Alloy steel
Shaft Material	Alloy steel
Blade Material	Chrome steel

2.2.1.4 Feedwater Pump Motor Drive

Type	Variable speed induction
Quantity	1
Horsepower	2,300 hp
Speed	3,600 rpm
Speed Increasing Gear Ratio	(TBD)

2.2.1.5 Feedwater Heaters No. 2A and 2B

Quantity	2
Type	Horizontal, 2-pass, U-tube
Feedwater Flow	1,250 gpm
Feedwater Pressure	2,254 psig
Feedwater Inlet Temperature	307°F
Feedwater Inlet Enthalpy	281 Btu/lb.
Feedwater Outlet Temperature	366°F
Feedwater Outlet Enthalpy	341 Btu/lb.
Steam Inlet Pressure	166 psig
Steam Inlet enthalpy	1,425 Btu/lb
Steam Inlet Temperature	798°F
Drain Outlet Temperature	315°F

Heat Exchange	32.4 x 10^6 Btu/hr
Pressure Drop (tube side-max.)	10 psi
Tubeside Design Pressure	2,400 psig
Tubeside Design Temperature	311°F
Shell Design Pressure	164 psig
Shell Design Temperature	155 psig
Shell Material	Carbon steel
Tube Material	Stainless steel

2.2.1.6 Feedwater Heaters No. 3A and 3B

Quantity	2
Type	Horizontal, 2-pass, U-tube
Feedwater Flow	1,250 gpm
Feedwater Pressure	2,244 psig
Feedwater Inlet Temperature	366°F
Feedwater Inlet Enthalpy	341 Btu/lb.
Feedwater Outlet Temperature	406°F
Feedwater Outlet Ethalpy	384 Btu/lb.
Steam Inlet Pressure	277 psig
Steam Inlet Enthalpy	1,483 Btu/lb.
Steam Inlet Temperature	918°F
Drain outlet Temperature	374°F
Heat Exchange	23.0 x 10^6 Btu/hr
Pressure Drop (tube side-max.)	10 psi
Tubeside Design Pressure	2,400 psig
Tubeside Design Temperature	366°F
Shell Design Pressure	260 psig
Shell Design Temperature	923°F
Shell Material	Alloy steel
Tube Material	Stainless steel

2.2.1.7 Feedwater Heaters No. 4A and 4B

Quantity	2
Type	Horizontal, 2-pass, U-tube
Feedwater Flow	1,250 gpm
Feedwater Pressure	2,234 psig
Feedwater Inlet Temperature	406°F
Feedwater Inlet Enthalpy	384 Btu/lb.
Feedwater Outlet Temperature	451°F
Feedwater Outlet Enthalpy	432 Btu/lb.
Steam Inlet Pressure	436 psig
Steam Inlet Enthalpy	1,332 Btu/lb.
Steam Inlet Temperature	650°F
Drain Outlet Temperature	414°F
Heat Exchange	25.5 x 10^6 Btu/hr
Pressure Drop (tube side-max.)	10 psi
Tubeside Design Pressure	2,400 psig

Tubeside Design Temperature	406°F
Shell Design Pressure	445 psig
Shell Design Temperature	655°F
Shell Material	Carbon steel
Tube Material	Stainless steel

2.2.1.8 Other equipment details may be found in their respective System Design Description:

High Temperature Economizer, Radiant Boiler	HR/SR
Channel, Combustor, Diffuser	MHD Power Train
Deaerator and Storage Tank	Condensate
Low Temperature Economizer	

2.2.2 Piping and Valves

Feedwater system piping is ASTM A 106 carbon steel with welded joints designed in accordance with ANSI B31.1 and ASME Boiler and Pressure Vessel Code. Flanged connections are used at the booster pump and other low pressure apparatus that may require removal for maintenance.

Provision is made for isolating each booster pump and boiler feedwater pump by valves in the suction and discharge lines. This provision facilitates the repair of a non-operational pump while the plant is operational.

Each heater string can be isolated by a motor-operated globe valve on the inlet and a motor-operated stop-check valve on the outlet of each heater string. For loads over 60 percent, feedwater can be bypassed if one set of heaters is out of service.

The stop-check valves represent the limit of ASME Boiler Code design for the piping system. Another motor-operated stopcheck valve is provided upstream of the HT economizer inlet.

Pump recirculation control valves are provided with isolation valves on the deaerator side only. Bypass valves are not provided for these control valves.

A pneumatically operated control valve is provided in parallel with the main stop valve at the HT economizer inlet. This valve is positioned from the feedwater flow control system.

A flow recirculation control valve is provided downstream of the MHD combustor cooling jacket, and is also positioned from the feedwater flow control system.

2.2.3 Electrical

Power for the booster pumps and the motor-driven boiler feedwater pump is from the 4,160 voltage plant service bus. Switchgear and motor starting equipment is provided for each motor.

Motor-operated valves are 460 volt, 3 phase, 60 Hz, with power supplied from a 480 volt motor control center.

2.2.4 Instruments, Controls, and Alarms

The Boiler Feedwater System is provided with appropriate locally installed instrumentation for indicating and transmitting feedwater pressure, temperature, and flow. These instruments are placed at points commensurate with good design practice for control and to monitor system performance (see Boiler Feedwater System Diagram 8270-1-521-302-081).

The majority of the control switches and instrument readouts for the system are located on the feedwater control board in the Main Control Room. Local control switches are provided at the respective motor control centers.

All pumps are monitored and controlled directly from the main control room. System equipment malfunctions, such as feedwater booster pump trip, or trip of a boiler feedwater pump or turbine (which will alarm in the control room), will require operator action.

Heater performance is monitored by the main control room computer. Automatic controls are provided to prevent turbine water induction if a heater tube failure occurs. Heater strings can be isolated and bypassed by actuating the control switch for the motor-operated inlet valves.

Direct pressure indicators are provided on the suction and discharge side of the feedwater booster pumps and the boiler feedwater pumps.

Direct reading pressure differential indicators are provided on the feedwater booster pump suction strainers, on each feedwater heater, and on the feedwater pump suction strainers.

Pressure test connections are provided at the common feedwater booster pump discharge, at the discharge of each boiler feedwater pump, and on the feedwater piping upstream of the HT economizer inlet.

Pressure transmitters are provided on the suction of each boiler feedwater pump for pressure indication in the main control room, for computer input, and to annunciate in the control room on low pressure. Pressure transmitters are provided on the discharge of each boiler feedwater pump for pressure indication in the main control room, and computer input. A pressure transmitter is provided on the main feedwater line upstream of the HT economizer inlet for pressure indication in the main control room, and computer input.

Pressure switches are provided on the discharge of each boiler feedwater pump to trip the associated turbine drive so that pump discharge pressure does not exceed the piping design pressure.

Boiler feedwater temperature is monitored at various stages of its flow. Thermometers, for local temperature indication, are installed on the suction of each feedwater booster pump. Thermocouples (or RTD's), for temperature

indication in the main control room are installed on the discharge of each boiler feedwater pump, and on the inlet and outlet of each feedwater heater. Thermowells, for the installation of test thermocouples, are installed on the suction of each feedwater booster pump; the discharge of each boiler feedwater pump; on the inlet and outlet of each feedwater heater; and on the feedwater line upstream of the HT economizer inlet. A temperature transmitter is installed on the main feedwater line upstream of the HT economizer inlet for temperature indication in the main control room, and computer input.

Level switches are installed on the deaerator storage tank to trip the booster pumps on very low level.

Orifice type flow elements are installed on each booster pump discharge and each boiler feedwater pump suction. A flow nozzle is installed on the feedwater line upstream of the HT economizer inlet. Flow elements, provided by the pump manufacturer, are installed in each boiler feedwater pump balance drum leak-off line.

The flow controllers associated with each booster pump discharge orifice provide signals to open the minimum flow recirculation valves. The flow transmitters are provided with local flow indicators.

The flow transmitters on the boiler feedwater pump suction lines serve two functions. The flow signals control the minimum flow recirculation valves, and provide control room indication of flow on the feedwater control board, and computer input.

The flow transmitters associated with the feedwater flow nozzle provide signals to the feedwater analog control system. Signals from the analog system provide control room computer indication of flow, in addition to a flow recorder mounted on the feedwater control board.

Flow test connections are provided at each flow element.

A three-element feedwater control is utilized to maintain water-flow input equal to feedwater demand. Steam flow, drum level, and feedwater flowrate feedback signals are utilized to keep drum level as constant as possible at all HR/SR Radiant Boiler loads and with varying feedwater pressure. In addition, a 70 percent minimum flow rate signal is imposed to maintain feedwater flow through the MHD combustor cooling water jacket.

The high pressure turbine first-stage shell pressure is used as a substitute variable for steam flow. The steam flow signal, which is the basic demand for feedwater flow, is summed with the output of the drum level controller and this summation output is the total feedwater demand signal to the feedwater flow controller. The flow controller compares the process variable signal of feedwater flow with the total feedwater demand signal and provides corrective action to the pump controllers and to the feedwater valve positioner.

Provision is made for pressure compensation to the drum-level system.

For the boiler feedwater booster pump, an alarm will occur under the conditions of low lubrication oil pressure, high vibration, high bearing metal temperature, or vibration. For the boiler feedwater pumps, an alarm will occur under the conditions of low lubrication oil pressure, high seal water injection return temperature, and high bearing metal temperature or vibration.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Booster pump/feedwater pump trip logic ensures feedwater pump protection by tripping a feedwater pump upon loss of booster pump power or suction pressure. This may also cause a unit trip or runback in load. A booster pump trip occurs on low deaerator level.

Additional alarm and trip functions associated with the turbine driver are covered in the "Extraction Steam System", System Design Description and Fluid System Diagram 8270-1-503-302-041.

To protect the pumps from overheating and cavitation during low load, minimum recirculation control is provided for each booster pump and boiler feedwater pump. Recirculation flow is controlled by differential sensors across an orifice located in the piping for each pump. The differential pressure corresponding to a preset flow rate controls the recirculation control valve to keep pump flow at its recommended minimum capacity.

The feedwater booster pump suction isolation valve limit switches will be interlocked with the associated booster pump motor to prevent starting the pump when the valve is not in the "open" position. Tripping will occur on motor overload, low lubrication oil pressure, or suction valve not fully open.

To protect the MHD channel from overheating, a feedwater recirculation line to the condenser is provided downstream of the MHD Power Train. A recirculation control valve operates in conjunction with the main feedwater control to maintain a minimum of 70 percent flow, regardless of drum level control signal. A breakdown orifice is installed in the bypass line to reduce the pressure and make it suitable for condenser conditions.

3.2 HAZARDS

No special hazards are considered to exist in the Feedwater System beyond those normally associated with high temperature, high pressure piping, and rotating equipment. Personnel should note that the automatic start of a standby pump can occur.

3.3 PRECAUTIONS

There are no special precautions for safe operation of the Feedwater System. Startup, normal operation and shutdown must be in accordance with instructions received from manufacturers furnishing equipment for this system.

4.0 MODES OF OPERATION

4.1 STARTUP

The feedwater system startup sequence is:

1. Deaerator storage tank level at normal operating point. Deaerator pegged and vented at 2 psig by use of auxiliary steam.

2. Booster pump minimum flow recirculation valves open.

3 Auxiliary steam available for sealing turbine, pegging deaerator, etc.

4. System is aligned for normal operation; i.e., necessary valves are in proper position, and system is filled and vented. With the deaerator at normal level the system may be filled by gravity and vented prior to any pump start.

5. Operational condensate system - condensate pumps on recirculation to condenser - circulating water pumps in operation. Condenser vacuum established.

6. A feedwater booster pump is started and cleanup recirculation is established through the booster pump discharge and back to the condenser.

7. Feedwater flow is established through the heater and bypass piping. Flow is alternated as necessary to flush each route. This flush is dumped to the condenser from a point upstream of the high temperature economizer inlet. This flow path is used to clean up and deaerate the water prior to sending the water to the HR/SR Radiant boiler. The water is satisfactorily clean for introduction to the radiant boiler when differential pressure has stabilized across a clean suction strainer, and water chemistry has reached satisfactory levels.

8. The motor-driven feedwater pump is started and recirculation is established through the pump recirculation system back to the deaerator. Booster pump cleanup line to the condenser must be closed prior to starting the feedwater pump.

9. The MHD Power Train may be fired at this point to start generation of steam in the HR/SR radiant boiler.

10. As the MHD system combustor is fired to increase HR/SR steam temperature and drum metal temperature, in accordance with prescribed rates, the steam piping and the main turbine casings are warmed.

11. When boiler drum conditions reach adequate pressure and temperature, steam may be used for the turbine shaft seals and to operate a turbine-driven feedwater pump in accordance with the starting requirements of the HR/SR Radiant Boiler and the main steam turbine.

12. **When unit megawatt load exceeds 40 percent, a turbine driven feedwater pump should be brought into service, and pump speeds paralleled. The second turbine driven pump may be started anytime following, and the motor driven pump put on standby.**

4.2 NORMAL OPERATION

During normal operation of the Feedwater System, the system is controlled automatically and monitored from the main control room. Booster pumps and all valve motors are operated from control switches located on the feedwater-condensate panel of the main board.

4.3 SHUTDOWN

Continuous feedwater delivery is required to maintain boiler drum level while bringing the plant to a shutdown.

4.4 SPECIAL OR INFREQUENT OPERATION

A complete loss of feedwater flow to the boiler could occur if power is lost to the feedwater booster pumps. This will cause a plant shutdown. Loss of condensate pumps will result in a forced shutdown unless restored in less than 5 minutes (deaerator storage tank capacity). On loss of one turbine driven feedwater pump, automatic load runback will commence while the standby motor-driven pump starts to restore flow. Loss of a booster pump will cause automatic runback of the main turbine driven pumps until the standby booster pump can be started and brought up to speed. Low suction pressure will automatically trip the boiler feedwater pumps and the unit.

A feedwater heater string may be removed from service by opening the bypass line and closing the inlet and outlet valves on the heater string to be isolated. Operating personnel must reduce the load according to the turbine manufacturer's instructions.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record direct indicating instruments and feedwater analysis at regular intervals per shift. The in-house computer will constantly monitor specified points to give a running check on performance which can alarm or be viewed periodically as desired in the plant control room.

5.2 INSERVICE INSPECTION

Visual inspection of all equipment, valves, instruments, pipe, pipe supports, etc., shall be carried out periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

All pumps, feedwater heaters and valves will be maintained and operated in accordance with the respective manufacturer's operating and maintenance instructions.

Computerized record keeping will be used to alert the operating personnel that pieces of equipment need an overhaul, repacking, cleaning, depending on the recommendations of the equipment manufacturer. In general parts will be replaced during planned shutdown if they are near the end of their recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. A certain amount of these parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
BOILER FEEDWATER SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Boile: Feedwater	8270-1-521-302-081

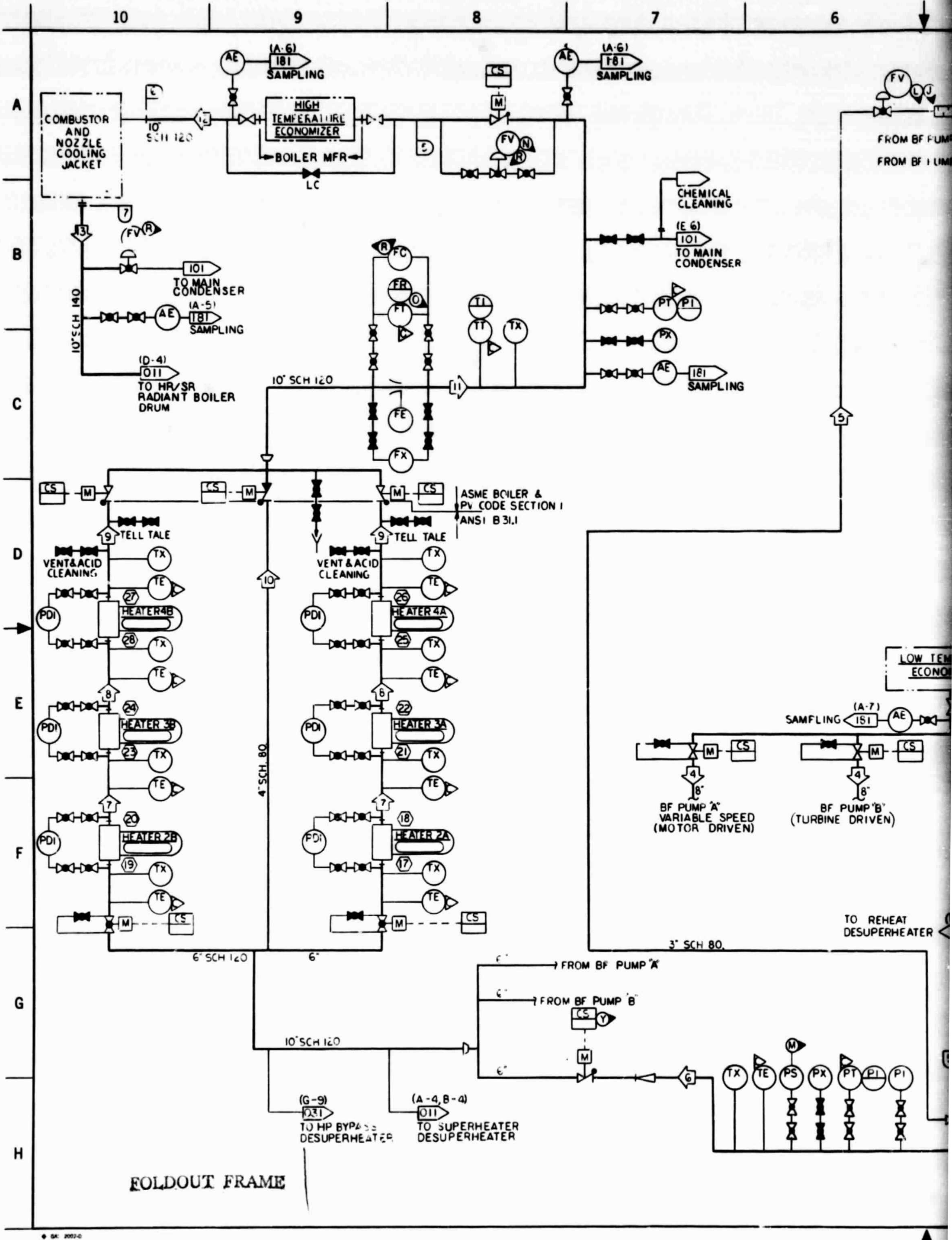
REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Main and Reheat Steam
Extraction Steam
Condensate

Plant Heat & Flow Balance Diagram

System Heat Balance	8270-1-540-314-001



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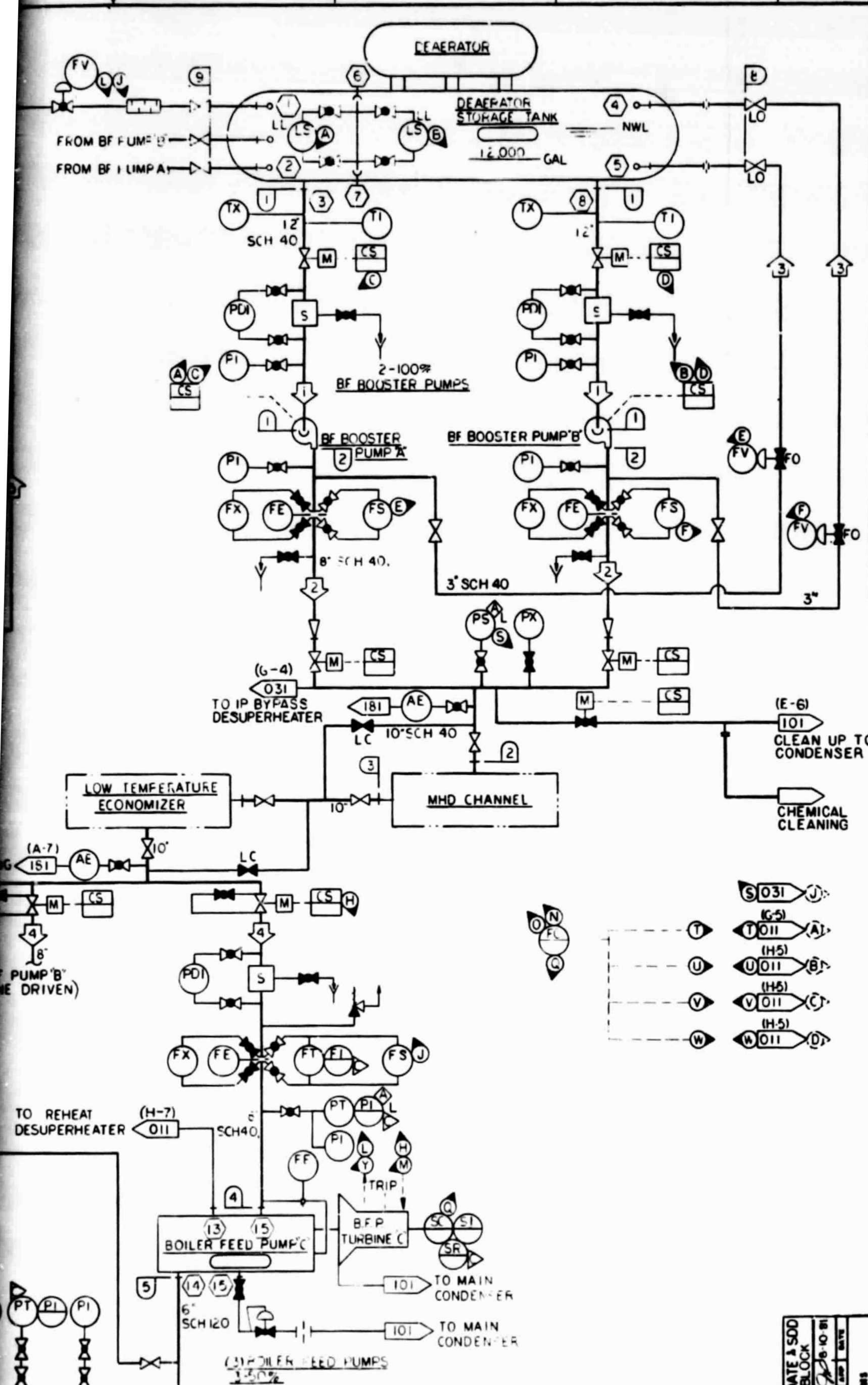

OPERATING DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	1071	1	213		BOOSTER SUCT.	
2	1071	235	214		BOOSTER DISCH.	
3	267	235	214		BOOSTER RECIRC.	
4	535	225	303		B.F.P. SUCT.	
5	134	2254	307		B.F.P. RECIRC.	
6	535	2254	307		B.F.P. DISCH.	
7	535	2244	366		FROM HTRS 2A&2B	
8	535	2234	406		FROM HTRS 3A&3B	
9	535	2224	451		FROM HTRS. 4A&4B	
10	535	2254	307		HEATER BYPASS	
11	1071	2,224	451		TO H.T. ECON.	
12	1071	2190	530		TO COMBUSTOR	
13	1071	2105	637		TO HR/SR BLR.	

DESIGN DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	1,125	50	225		A106, GR.C	
2	1,125	275	225		A106, GR.C	
3	1,125	300	300		A106, GR.C	
4	562	250	310		A106, GR.C	
5	562	2,375	325		A106, GR.C	
6	1,125	2,300	535		A106, GR.C	
7	1,125	2,225	650		A106, GR.C	
8	261	275	220		A106, GR.C	
9	141	2375	350		A106, GR.C	

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	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

BOILER FEEDWATER SDD-081

200 MWe

DOE - NASA

MHD PROJECT OFFICE — APPD. H. RIGO

LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135 — DATE 9-25-81

GILBERT ASSOCIATES, INC.
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SYSTEM DESIGN DESCRIPTION

SDD - 101

CONDENSATE SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-511-302-101

R. B. Jensen 2/12/81

SYSTEM ENGINEER DATE

T C Reitz 2-12-81

Harry Flanders 2/12/81

REVIEWED DATE

APPROVED DATE

Revision: 1
Date: September 25, 1981
Approved:

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CONDENSATE SYSTEM

TABLE OF CONTENTS

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Condensate System as depicted on Fluid System Diagram 8270-1-511-302-101, Condensate. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Condensate System is designed to pump condensed steam (condensate) from the hotwell of the main condenser through the main turbine steam seal exhauster-condenser, the condensate demineralizer, and to the deaerating heater (deaerator) during all modes of operation.

1.2 SYSTEM INTERFACES

Major equipment components involved with the Condensate System include four condensers, condensate (or hotwell) pumps, turbine steam seal exhauster-condenser, demineralizer, deaerator, steam jet air ejector condensers, and condensate storage tank. The Condensate System interfaces with other major systems such as Boiler Feedwater, Extraction Steam, Feedwater Heater Drips, and indirectly interfaces with the following systems:

Bypass and Startup
Plant Makeup Water
Condenser Air Removal
Sampling
Closed Cycle Cooling Water
Main and Reheat Steam

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components and piping design. Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides used by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)

6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures, and "pipe sizing" flow rates are taken from the plant heat and flow balance diagram and tabulated on the fluid system diagram 8270-1-511-302-101. Flow rates are those occurring during main turbine valves wide open with the Heat Recovery/Seed Recovery (HR/SR) steam outlet at Maximum Continuous Rating conditions. Condensate pipe sizing is based on pressure drop and/or water velocity in the piping which is limited to 10 feet per second.

The piping is all welded construction in accordance with ANSI B31.1. Carbon steel is used throughout the system. Valves are compatible with the piping and in accordance with ANSI B16.5 and B16.34.

The condenser shells and circulating water-boxes, the deaerator, and deaerator storage tank designs are in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, latest edition, and the HEI Standards.

The condensate storage tank design is in accordance with AWS D5.2 (AWWA D100) Standards for Steel Tanks, Standpipe, Reservoirs and Elevated Tanks for Water Storage.

The Condensate System is designed to meet the flow and pressure requirements at all expected conditions and to provide stable operation during the most severe transient condition which may occur on a full load unit trip.

2.0 DESIGN DESCRIPTION

The Condensate System begins at the main condenser and terminates with the deaerator and deaerator storage tank. The system includes the condensers, condensate (or hotwell) pumps, heat exchangers, demineralizer, deaerator and interconnecting piping. Branches from the piping are provided for condensate services, makeup and storage.

2.1 SUMMARY DESCRIPTION

Exhaust steam from the steam turbine generator and the two boiler feedwater pump turbines exhausts directly into the main condenser. There are two Oxidant air compressor turbines and one Air Separation Unit (ASU) air compressor turbine, each with its own condenser. The exhaust steam from each turbine condenses and falls to the bottom of the condenser. Condensate from all the compressor condensers drains to the main condenser. Two 100 percent capacity mechanical vacuum pumps are provided to evacuate non-condensables from the condensers and maintain vacuum at all loads. Additonal backup is provided by a two-stage steam jet air ejector, with inter- and after-condensers, designed to operate with cycle steam.

Three 50 percent capacity condensate pumps are provided to pump the condensate from the main condenser hotwell to the deaerator. The piping between the hotwell and pumps contains isolation valves, drains and strainers. For protection, each pump discharge is equipped with a pressure actuated minimum flow recirculation line back to the condenser.

Condensate passes through a steam seal exhauster-condenser, a blowdown cooler, and the demineralizer before reaching the deaerator. In this section of piping are connections for various condensate services, including miscellaneous condensate uses such as boiler fill, makeup to the mechanical vacuum pumps, to the steam jet air ejector, valve sealing water, pump gland water, closed cycle cooling makeup, main turbine exhaust hood cooling spray, sampling, and condensate transfer and storage. A flow controller in the condensate line is set to operate a system recirculation valve to provide the minimum allowable flow for the steam seal exhauster-condenser during times of low condensate demand. This recirculation returns to the main condenser.

The deaerator is a horizontal tray type with a horizontal storage tank. The condensate flows into the deaerator, where entrained oxygen and carbon dioxide are removed by heating with extraction steam. The feedwater booster pumps take suction from the deaerator storage tank to supply the Boiler Feedwater System.

A condensate storage tank is necessary to accommodate surges in the system and to provide makeup storage. Excess condensate from the system flows to the storage tank through the condensate spillover valve, which opens when condensate level in the hotwell is above normal.

Makeup to the condensate system enters the condenser through the normal makeup valve which opens on low hotwell level. With the unit operating, the static head of the condensate storage tank and the negative pressure of the condenser will provide sufficient flow for the makeup requirements of the condenser. An emergency makeup valve is also provided for higher makeup requirements such as condenser filling, and for backup if the normal makeup valve does not function properly. The condensate transfer pump can be used for condenser filling when the unit is not under vacuum or when a higher makeup rate is desired.

Demineralized water from the makeup demineralizer enters the condensate system through a makeup valve which opens on low condensate storage tank level and closes on high condensate storage tank level. When the unit is down, makeup demineralized water can be routed directly to the condensate storage tank.

The Condensate System is provided with appropriate instrumentation for sensing flow, pressure, and temperature at points commensurate with good design practice to monitor system performance.

Level control instrumentation is provided for maintaining design water levels in the deaerator storage tank, condensate storage tank, and the condenser hotwell. Flow control instrumentation is used to control condensate pump discharge recirculation flow back to the condenser.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment components are the steam s ::ace condensers, the condensate pumps, the demineralizer, and the deaerator.

2.2.1.1 Condensers

Each steam surface condenser has two water passes with divided water boxes. The condenser shell and water boxes are to be specified using ASME and HEI code design requirements.

PERFORMANCE AND MATERIALS

Condenser	Main Turbine Generator & BFW Pump Turbines	Oxidant Comp. Turbines	ASU Comp. Turbine
Number	1	2	1
Surface, sq. ft.	57,000	7,600	8,000
Tubes	Copper-nickel	Copper-nickel	Copper-nickel
-Size, OD-BWG	7/8 in. - 18	7/8 in. - 18	7/8 in. - 18
-Length, feet	25	20	20
Water, gpm	51,200	8,500	8,900
-Temp. in, °F	69	69	69
-Temp. out, °F	92	92	92
Vacuum, in. Hg. abs.	2.0	2.5	2.5
Condenser shell	Fab. steel	Fab. steel	Fab. steel
Water boxes	Fab. steel	Fab. steel	Fab. steel
Tube sheet	Copper-nickel	Copper-nickel	Copper-nickel
Tube supports	Steel	Steel	Steel

2.2.1.2 Demineralizer

The Condensate Demineralizer functions to polish condensate from the main condenser hotwell. It is also used for startup and cleanup recirculation prior to admitting feedwater to the HR/SR. The Demineralizer removes small amounts of dissolved solids and suspended iron oxide during normal operation. It also provides some removal for higher amounts of feedwater contaminants from the condenser cooling water should a condenser tube leak occur.

The system consists of one deep bed demineralizer and one spare unit each rated at 100 percent of the condensate flow. Each demineralizer is provided with a minimum 3-foot bed of mixed ion exchange resin and some inert resin for optimum bed separation during regeneration.

A high differential pressure alarm across the demineralizer requires operator action. Should the operator fail to acknowledge the high alarm, a high-high differential pressure alarm is actuated to automatically open a full-flow bypass control valve.

The equipment is designed for resin transfer and external regeneration of the ion exchange resins using sulfuric acid and sodium hydroxide. Three regeneration vessels are provided, i.e., Cation Regeneration/ Separation Tank, Anion Regeneration Tank, and Resin Storage Tank. Regeneration chemicals will be taken from Makeup Demineralizer Acid and Caustic Storage Tanks.

The system is provided with a control panel suitable for pushbutton automatic regeneration of the ion exchange resins. Sample analysis and monitoring are provided for flow rate, conductivity, pH and sodium in the demineralized effluent.

Pressure vessels are rated 150 psig ASME code. Suitable corrosion-resistant materials are used for valves and piping.

2.2.1.3 Deaerator and Storage Tank

Type	Horizontal, spray tray type, with internal direct contact stainless steel vent condenser, and carbon steel plate storage tank.	
Operating pressure	15.04	psia
Outlet feedwater flow	1,070,992	lbs/hr
Temperature of flow	213.2	°F
Enthalpy of flow	181.3	Btu/lb
Deaerator shell diameter	7-0	feet-inches
Overall Length	18-0	feet-inches
Storage tank diameter	10-8	feet-inches
Overall length	25-6	feet-inches
Operating capacity	12,000	gallons
Storage capacity	5	minutes

2.2.1.4 Condensate Pumps

Type	Vertical, centrifugal, multi-stage
Number	Three
Capacity	950 gpm
TDH	200 feet
NPSH	10 feet
Brake horsepower	75

Materials

Casing	**Carbon steel**
Impellers	**Stainless steel**
Shaft	**Stainless steel**
Bearings	**Bronze**

2.2.2 Piping and Valves

The condensate system valves are arranged for isolation and bypass of major equipment except the seal steam exhauster-condenser.

The condensate system piping is carbon steel with welded joints, in accordance with the piping standards specified in Section 1.3.1.

Flanged connections are used on pumps, vacuum pumps, strainers, and steam seal exhauster-condenser, in order to facilitate removal for maintenance.

Valve body materials are compatible with pipe materials.

2.2.3 Electrical

Power for the condensate pump motors will be 460 volt supplied from 480 volt, 3 phase, 60 Hz motor control centers.

Motor-operated valves are typically 460 volt, 3 phase, 60 Hz, with power supplied from 480 volt motor control centers.

Power for instrumentation is taken from distribution centers.

2.2.4 Instruments, Controls, and Alarms

The Condensate System is provided with appropriate instrumentation for sensing flow, pressure, and temperature at points commensurate with good design practice to monitor system performance.

Level control instrumentation is provided for maintaining design water levels in the deaerator storage tank, condensate storage tank, and the main condenser hotwell. A pressure switch is used to control condensate pump discharge recirculation flow back to the main condenser. System recirculation is controlled by flow sensing instrumentation to maintain minimum flow through the seal steam exhauster-condenser.

Main condenser pressure is 2.0 in. Hg. abs. at full load conditions. A pressure switch on the condenser provides a signal to trip the main turbine under poor condenser vacuum conditions. The mechanical drive turbine condensers are rated at 2.5 in. Hg-abs. and have individual pressure switches.

Alarms are provided for poor condenser vacuum, low condensate pump seal water pressure, condenser level high/low, deaerator storage high/low, condensate storage tank high/low and demineralizer differential pressure high.

Provisions are made for analysis sampling of condensate from main condenser hotwell, condensate pump discharge header, and the condensate storage tank.

Mechanical vacuum pump operation is initiated by the operator at the local panels or from the main control room. After initiation, vacuum pump operation is automatic throughout the design range of the vacuum pumps. The local panels include alarms for monitoring the performance of the vacuum pumps, with common annunciation to the main control room.

After the initial vacuum is established, and condensate system valves are aligned for normal operation, the system is monitored from the main control board for startup, shutdown, and normal operation.

The condensate pumps are operated with control switches located on the main control board.

The condensate transfer pump is arranged for local starting and stopping.

The mechanical vacuum pumps are supplied with a sealing and cooling water system, and control system.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The other major equipment operating limits and protective devices are described in System Design Descriptions noted in Section 1.2.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Condensate System beyond those normally observed in conjunction with high temperature and high pressure piping.

3.3 PRECAUTIONS

The requirements and recommendations for the prevention of water induction into the steam turbines (ASME Standard No. TDP-1-1980) has been included in the system design and must be followed in the operation of the Condensate System.

4.0 MODES OF OPERATION

4.1 STARTUP

The Condensate System is one of the first systems to be placed in operation during plant startup. The system supplies cooling water to the steam seal exhauster-condenser, to a blowdown cooler, sealing water to pump seals, boiler fill water, and miscellaneous condensate makeup services.

Startup from a "dry" state involves the filling of the Condensate, Boiler Feedwater Systems and the HR/SR. The condenser hotwell is filled first by opening the fill valve and admitting water from the condensate storage tank. The transfer pump may be used for fast filling. Once the hotwell is filled, the condensate pumps may be started and the Condensate System, from the condenser to the main system shutoff valve and bypass line, is vented and filled. Once flow is established through the bypass line from the Deaerator, the Boiler Feedwater System may be activated.

For a startup from cold shutdown with the main condenser hotwell filled, the initial step is to vent and fill the Condensate System. The condensate pumps are started with main system shutoffs closed and the control valves open. With the reduced flow through the empty system, system fill is accomplished without causing severe water hammer. After the Condensate System is filled and vented, the plant clean-up cycle can begin.

During the main turbine warm-up, and with the unit on turning gear, sealing steam is supplied to the turbine glands, the condenser vacuum pumps are started, auxiliary steam is admitted to the deaerator and the condensate is recirculated until the oxygen content, solids content, and the pH are within prescribed limits.

The level in the main condenser hotwell is maintained by level controls and makeup from the makeup demineralizer or spill to the condensate storage tank. One set of level controls governs the amount of makeup or spill required. The system requires no operator action after startup except normal surveillance.

4.2 NORMAL OPERATION

The normal load range of the unit, and consequently the Condensate System, is categorized as base load with very little part load operation below 75 percent. The Condensate System is capable of operating satisfactorily without special operator action in the event of load changes on the Unit.

During normal operation, at loads above 75 percent main unit load, two 50 percent condensate pumps are used. The standby condensate pump is arranged for automatic start in the event of an electrical trip of a running pump.

4.3 SHUTDOWN

Equipment may be removed from service by closing isolation valves and opening bypass valves (except the seal steam exhauster-condenser) in accordance with the equipment manufacturer's instructions.

A high-high water level in the deaerator storage tank or low water level in the main condenser hotwell causes closure of the deaerator inlet isolation valve. A very low condenser hotwell level will cause a trip of the condensate pumps.

Two condensate pumps must be kept in service until the condensate/feedwater flow requirement has fallen below 50 percent of full load, and at least one condensate pump must remain in operation on recirculation until the gland seal exhauster-condenser is shutdown. The Condensate and Boiler Feedwater Systems must be in operation whenever heat is flowing through the Topping cycle.

4.4 SPECIAL OR INFREQUENT OPERATION

The Condensate System valves and controls are designed to prevent water induction and steam reverse flow from entering the main steam turbine following a turbine trip. A high feedwater level in the deaerator diverts incoming drains directly to the main condenser. A high-high level closes the non-return valves and the stop valve in the extraction steam line and opens the extraction piping drain valves. This effectively isolates the deaerator from the Extraction Steam System and prevents the possibility of water induction into the main steam turbine through the extraction piping.

During a steam dump to the main condenser, the Condensate System may be affected by a deterioration in vacuum, an increase in condensate temperature, and a fluctuation of level in the condenser hotwell.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

An in-house computer system will monitor significant data points in the Condensate System to parallel the automatic controls. This will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance shall be carried out on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

All piping, valves, controls, gauges, pipe supports, etc., shall be inspected periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking etc., depending on the recommendations of the equipment manufacturer. In general, parts will be replaced during planned shutdown if near the end of their recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CONDENSATE SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

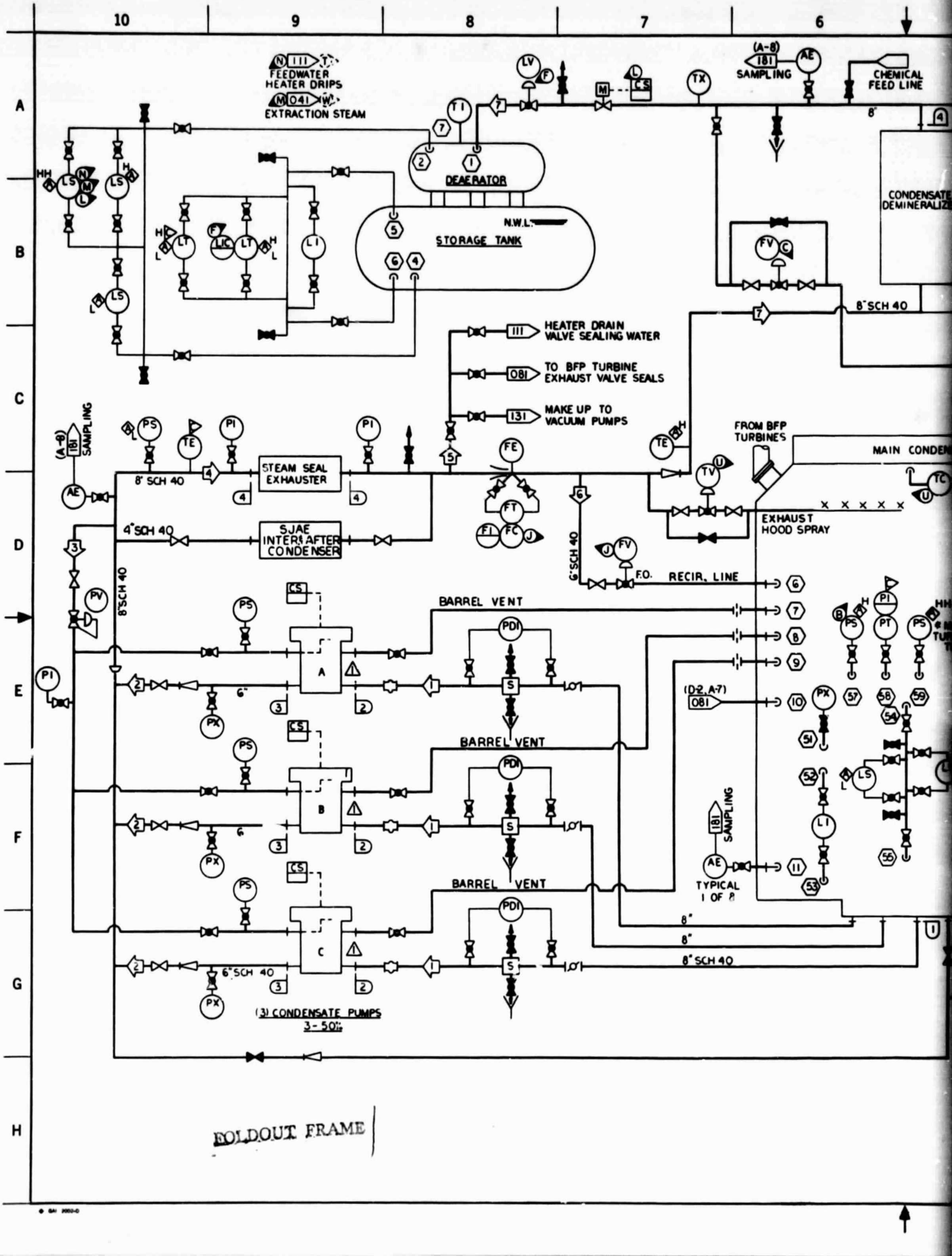
Fluid System Diagrams	Diagram No.
Condensate	8270-1-511-302-101

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions
- Extraction Steam
- Boiler Feedwater
- Feedwater Heater Drips

Plant Heat & Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001

ASME Standard No. TDP-1-1980 "Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation"; Part 1 - Fossil Fueled Plants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A
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C
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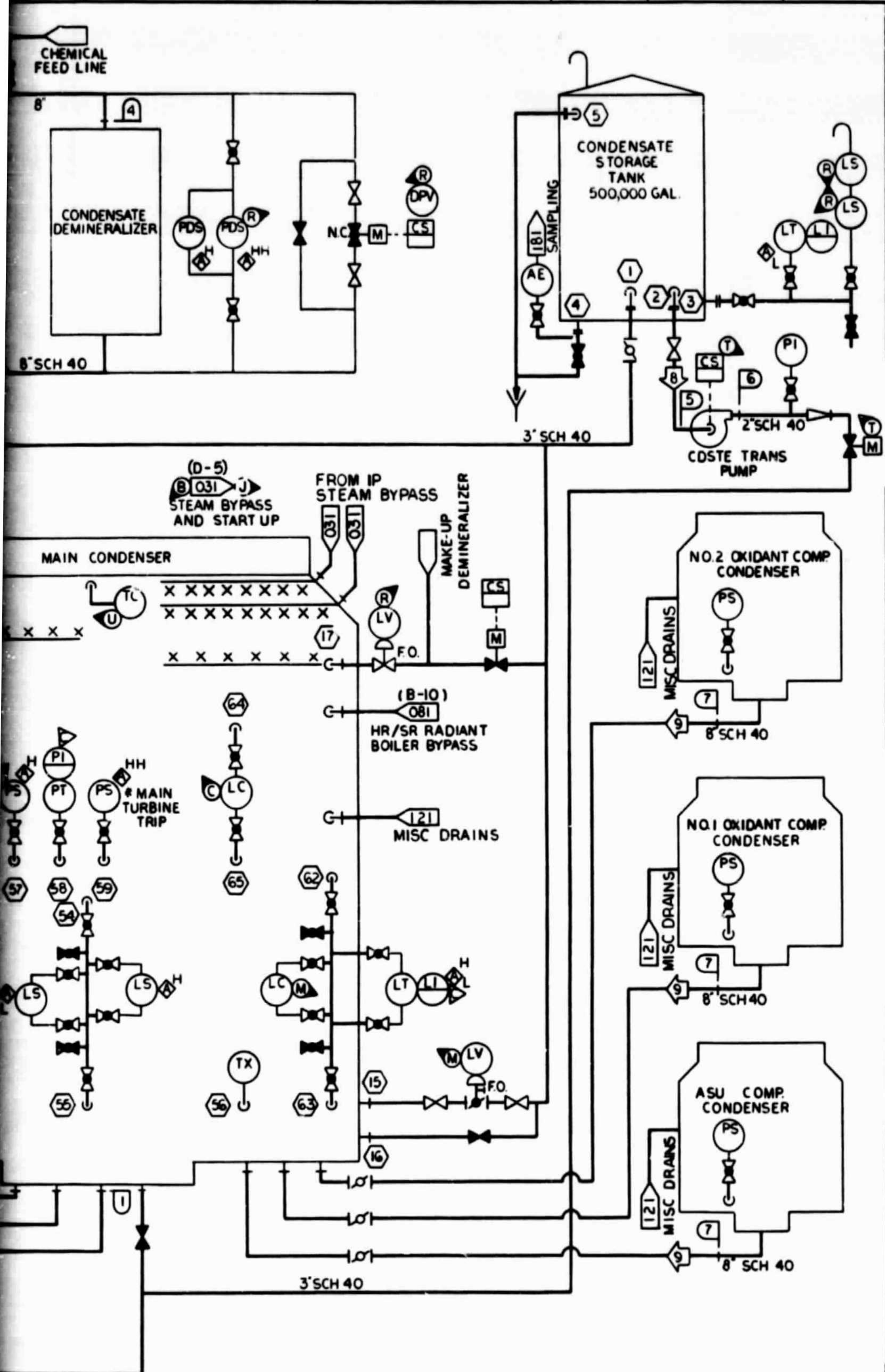
E
F
G
H
FEEDWATER HEATER DRIPS
EXTRACTION STEAM
DEAERATOR
STORAGE TANK
N.W.L.
SAMPLING
CHEMICAL FEED LINE
CONDENSATE DEMINERALIZE
8" SCH 40
HEATER DRAIN VALVE SEALING WATER
TO BFP TURBINE EXHAUST VALVE SEALS
MAKE UP TO VACUUM PUMPS
FROM BFP TURBINES
MAIN CONDE
STEAM SEAL EXHAUSTER
SJAE INTER & AFTER CONDENSER
4" SCH 40
8" SCH 40
6" SCH 40
EXHAUST HOOD SPRAY
RECIR. LINE
F.O.
BARREL VENT
TYPICAL 1 OF 8
(3) CONDENSATE PUMPS 3-50%
FOLDOUT FRAME



OPERATING DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	424	-13	101		CDSTE. PUMP SUCT.	
2	424	45	101		CDSTE. PUMP DISCH.	
3	—	45	101		CDSTE. SEAL	
4	848	45	101		DISCH HEADER	
5	99	40	103		VALVE SEALS	
6	424	40	103		MAIN RECIRC.	
7	848	-10	103		CDSTE. TO D/A	
8	75	14	80		TRANS. PUMP SUCT.	
9	150	-13	101		ASU & OXIDANT CDSTE	

DESIGN DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	933	50	200		A106, GR B	
2	466	50	200		A106, GR B	
3	466	100	200		A106, GR B	
4	933	100	200		A106, GR B	
5	75	50	200		A106, GR B	
6	75	100	200		A106, GR B	
7	105	50	200		A106, GR B	

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I.D. NO. C-373-010

DATE	RELEASED FOR	ENGR.
3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

CONDENSATE SDD-101

200 MWe

DOE - NASA

MHD PROJECT OFFICE

LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135

APPD. H. RIGO

DATE 9-25-81

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA

SCALE NTS

8270-1-511-302-101

DRAWING NUMBER REV 1

REV	MADE	CHKD	APP	DATE	REVISIONS
1	NL	PRJ		8-10-81	CHANGED CONDENSATE PUMPS TO A, B & C, ADDED H RIGO-DATE & SDD NO IN TITLE BLOCK

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SYSTEM DESIGN DESCRIPTION

SDD-111

FEEDWATER HEATER DRIPS SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

4

FLUID SYSTEM DIAGRAM NO. 8270-1-525-302-111

R. B. Jensen — Feb. 5, 1981

SYSTEM ENGINEER — DATE

T C Reitz — Feb 27, 1981

[illegible] — Feb [illegible], 1981

REVIEWED — DATE

[illegible] — [illegible]

APPROVED — DATE

Revision: 1

Date: ~~September 25,~~ 1981

Approved: [illegible]

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FEEDWATER HEATER DRIPS SYSTEM

TABLE OF CONTENTS

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Feedwater Heater Drips System as depicted on Fluid System Diagram 8270-1-525-302-111, Feedwater Heater Drips. The document includes descriptions of system functions, interfaces with other system equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Feedwater Heater Drips System is designed to maintain normal water level in the regenerative feedwater heaters and to control the flow of cascading condensate back to the deaerating heater (deaerator). The system also serves to prevent turbine water induction (ASME Standard No. TDP-1-1980) during any mode of operation.

Normal drip control flow is divided per the two heater strings and cascades from heaters 4A and 4B to 3A and 3B, to 2A and 2B and then to a Low Pressure (LP) flash tank. Steam from the flash tank is directed to the deaerator. Water from the flash tank goes to the deaerator storage tank.

Provisions have been made to drain each heater directly to the main condenser during startup or very high water level conditions in the heater.

1.2 SYSTEM INTERFACES

Major equipment components involved with the Feedwater Heater Drips System include the feedwater heaters, deaerator and storage tank, LP flash tank, and the main condenser. These components are described in other System Design Descriptions which interface with the Feedwater Heater Drips System, namely Boiler Feedwater and Condensate. The Feedwater Heater Drips System also interfaces with the Sampling System and Extraction Steam System.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)

4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures, and flow rates are taken from the unit heat and flow balance diagram and tabulated on the Fluid System Diagram 8270-1-525-302-111. Flow rates are those occurring during turbine valves wide open with the Heat Recovery/Seed Recovery (HR/SR) steam outlet at maximum continuous rating conditions. Feedwater Heater Drips System pipe sizing is based on pressure drop along with water velocity limited to 6-10 feet per second, and steam velocity limited to 1,000 feet per minute per inch of internal diameter (with a maximum steam velocity of 15,000 feet per minute). Flashing water/steam mixtures are limited by energy/density criteria.

2.0 DESIGN DESCRIPTION

2.1 SUMMARY DESCRIPTION

The Feedwater Heater Drips System consists of an LP flash tank, piping, valves, and controls. The major equipment components are covered in other System Design Descriptions.

2.2 DETAILED DESCRIPTION

The Feedwater Heater Drips System is related directly to the feedwater system and the condensate system, as covered by System Design Descriptions for Fluid System Diagrams 8270-1-521-302-081 (Boiler Feedwater System), and 8270-1-511-302-101 (Condensate System). The drips are condensed extraction steam and contain a large amount of recoverable heat.

2.2.1 Major Equipment

There are three extraction stages with closed, regenerative (shell and tube) heaters and one stage utilizing a direct contact (mixing) heater (deaerator). The extraction stages are arranged in series and the heaters are numbered starting from the lowest turbine extraction pressure.

As depicted on Fluid System Diagram No. 8270-1-525-302-111, Feedwater Heater Drips, the first stage of heating is in a mixing type heater called the deaerator, and all of its drains are fed to the feedwater booster pumps. The next three stages of heating, Nos. 2, 3, and 4, consist of two 50 percent parallel flow circuits with feedwater heaters 2A, 3A, and 4A in series, and 2B, 3B, and 4B in series.

Boiler feedwater heater level controls are designed and arranged to assure safe operation from startup through the full load range, and to assure smooth shutdown.

The feedwater heater drips are arranged in a cascade type system. The drips from each heater cascade to the next lower pressure heater. The normal sequence of operation is for heater 4A to drain to 3A, to 2A, to the LP flash tank, then to the deaerator, and 4B, to 3B, to 2B, to the same flash tank, then to the deaerator where the drains assist in heating the incoming condensate.

The heaters are arranged to cascade normally from part load of approximately 20 percent to full load. To assure proper draining during startup, low load, and emergency conditions, each heater drip outlet has an alternate, independent, high level controlled drain which goes to the main condenser. During low load operation, when sufficient shell pressure may not be available for normal cascading, high level alarms will be activated in the control room and the high level drains are opened to the condenser. These alarms should clear above approximately 20 percent load.

For the case where a string of 3 half sized heaters must be removed from service for maintenance, the system is designed such that the other string of heaters continues to operate normally with less overall recovery of heat.

The boiler feedwater heating system, including drip controls, are so arranged that a string of heaters may be bypassed and removed from service for maintenance during plant operation. The heater string may be removed from service by opening the feedwater bypass valve, closing the feedwater and extraction steam isolation valves, and closing the drip control valves to the LP flash tank and to the main condenser.

The turbine may be operated for emergency periods with a string of heaters out of service provided the turbine generator loading does not exceed the maximum guaranteed output, or exceed the design allowables of any parts or equipment.

2.2.2 Piping and Valves

The Feedwater Heater Drips System piping is designed with welded joints in accordance with ANSI B31.1. Piping materials are in accordance with ASTM specification A106, carbon steel. Valve body materials are compatible with pipe materials.

The drain valves are diaphragm actuated control type. The block valves are gate type. The non-return valves, from the flash tank to the deaerator, are free flowing, swinging disc types. Instrumentation valves are globe type.

2.2.3 Electrical

Solenoid valves will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls, and Alarms

Heater drip controls are designed to comply with the ASME Standard No. TDP-1-1980 turbine water induction prevention recommendations.

The following level detection and control devices are associated with each heater:

- Local level indicator
- Pneumatic level controller to modulate the normal drain valve to the next heater
- Pneumatic level controller to modulate the alternate drain valve to the condenser
- Low level switch for alarm only
- High level switch for alarm only
- Very high level switch to close the drain valve from the previous heater, trip the extraction non-return valve, operate the extraction steam isolation valves associated with the affected heater and initiate a very high level alarm.

Drain temperatures from each feedwater heater are monitored for performance as inputs to the computer.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Operating procedures based upon plant design and in accordance with the equipment manufacturer's instructions, will be followed. Feedwater heaters and the LP flash tank will be supplied with safety and relief valves.

3.2 HAZARDS

No special hazards exist other than those normally associated with high temperature pressurized piping systems. Automatically operated valves and arrangement of level controls and drains will prevent the possibility of water induction into the main steam turbine and reduce post-trip overspeed potential.

3.3 PRECAUTIONS

Extraction line drain valves must be opened before startup.

High water level in the heater will actuate closure of non-return extraction valves and motor operated stop valves. This is in accordance with the System Design Description for the Extraction Steam System covering the extraction steam valves.

Scheduled inspection, calibration, and preventive maintenance procedure must be followed during normal operation of the plant.

4.0 MODES OF OPERATION

4.1 STARTUP

During low load, each of the heaters will drain independently to the condenser, through the high level emergency control valve until the extraction pressures are sufficient for normal cascading. As turbine load increases, the steam pressure differential between heaters increases to overcome the static pressure head, pipe friction, and control valve pressure drop from one heater to the next.

4.2 NORMAL OPERATION

Level indicators and high and low level alarm switches provide indication that heaters are or are not operating normally and efficiently within the water level range prescribed by the heater manufacturer. Refer to section 2.2.4 "Instruments, Controls, and Alarms" for description of control valve and level switch operation.

Level control valves will operate normally and automatically by cascading from the highest pressure heater to the lowest pressure heater from about 25 to 100 percent turbine generator load rating. Below this load, heater drips will depend upon the high level control valve to dump to the main condenser depending upon the extraction steam differential pressure between the various stages and the difference in elevation between heaters.

4.3 SHUTDOWN

At low unit load (below 25 percent), the steam pressure in heaters is not sufficient to send drains to the deaerator because the differential pressure between heaters is insufficient to overcome the static leg associated with the difference in elevation. Therefore, increasing water level in the heater opens the alternate drain valve to the main condenser.

Heaters are taken out of service by motor-operated feedwater bypass valves. The outlet motor operated stop check valve is then secured after opening the bypass, as described in the Boiler Feedwater System Design Description for Fluid System Diagram 8270-1-521-302-081.

4.4 SPECIAL OR INFREQUENT OPERATION

Level alarms provide warning in the control room that heaters are operating outside the water level range prescribed by the heater manufacturer. These consist of a low water level switch, a high water level switch and a very high level switch which alarm in the main control room. In addition to alarming, the very high level switch initiates the following functions for prevention of water induction into the main steam turbine:

Closes the drain valve from the previous heater.
Closes the motor operated extraction valve to the heater.
Opens the alternate drain valve to the condenser.
Trips the extraction non-return valves to the heaters.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Indicating instruments are supplied for each heater as well as points transmitted to the computer. Plant operators record this information on a shift basis. The operator's log is used to calculate performance as a check on the computer output.

5.2 INSERVICE INSPECTION

Heater systems are inspected for leaks as a check on operation. High water level control valves are provided with inlet stop valves only. The downstream drain piping temperature must be checked during operation to determine if maintenance will be required during the next scheduled plant shutdown. This check will be for abnormally high temperature or noise.

The condition of the target plate downstream of each normal operating drip control valve must be checked periodically.

All high and low level alarms must be checked on a routine basis. Water level should be checked daily by the operating personnel.

5.3 PREVENTATIVE MAINTENANCE

A routine preventative maintenance schedule must be adhered to. This includes inspection and calibration of instruments, controls, and valves to ensure they are operating within their prescribed range. Provisions have been made to enable doing this during normal plant operation.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide plant personnel in the maintenance of any piece of equipment. If necessary, the manufacturer can provide a service engineer to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will provide lists of recommended spare parts. Critical parts and parts requiring long lead (delivery) times will be kept in inventory at the plant.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FEEDWATER HEATER DRIPS SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Feedwater Heater Drips	8270-1-525-302-111

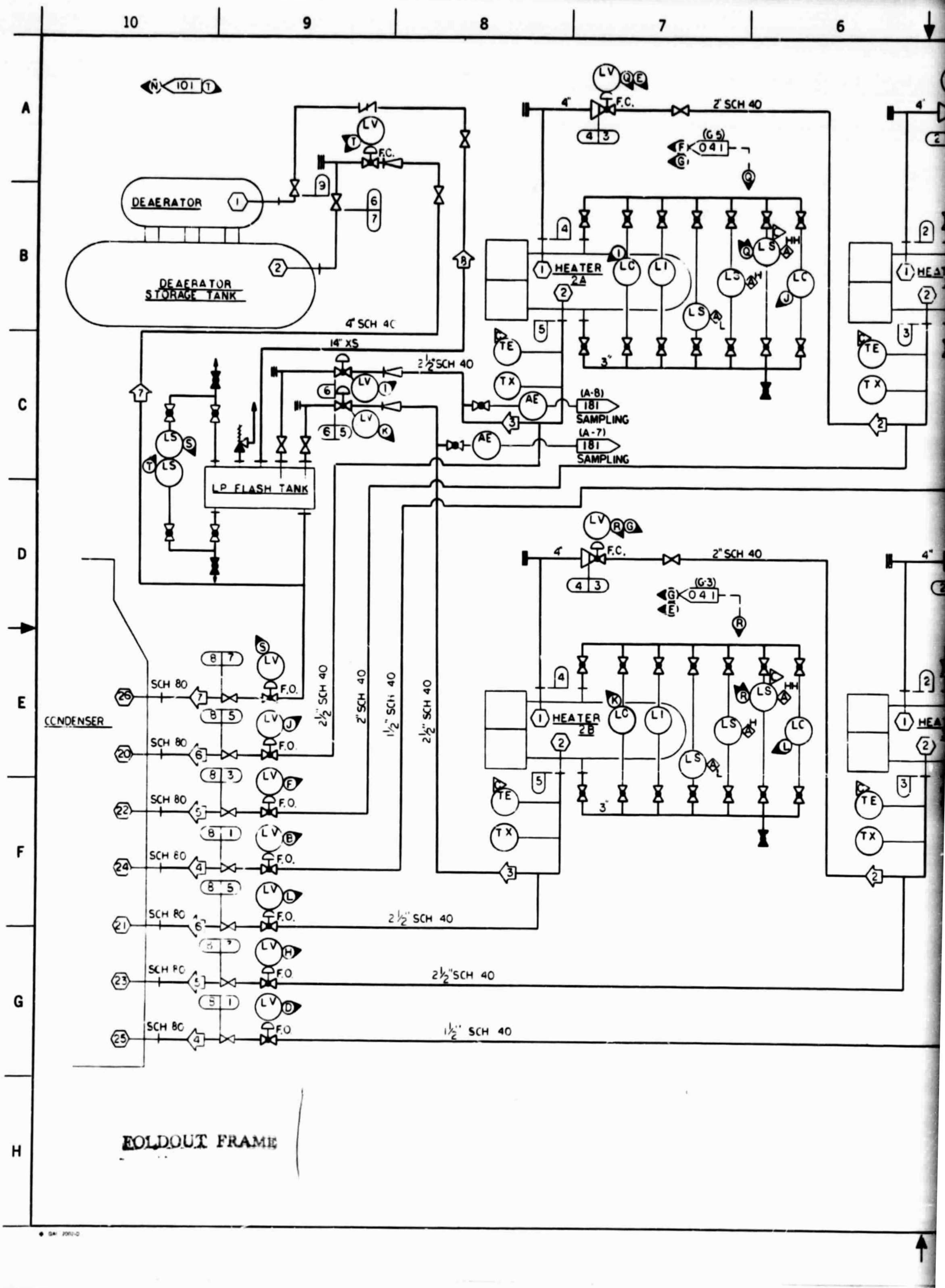
REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions

Extraction Steam
Boiler Feedwater
Condensate
Sampling

Plant Heat & Flow Balance Diagram
System Heat Balance — 8270-1-540-314-001

ASME Standard No. TDP-1-1980 "Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation"; Part 1 - Fossil Fueled Plants.



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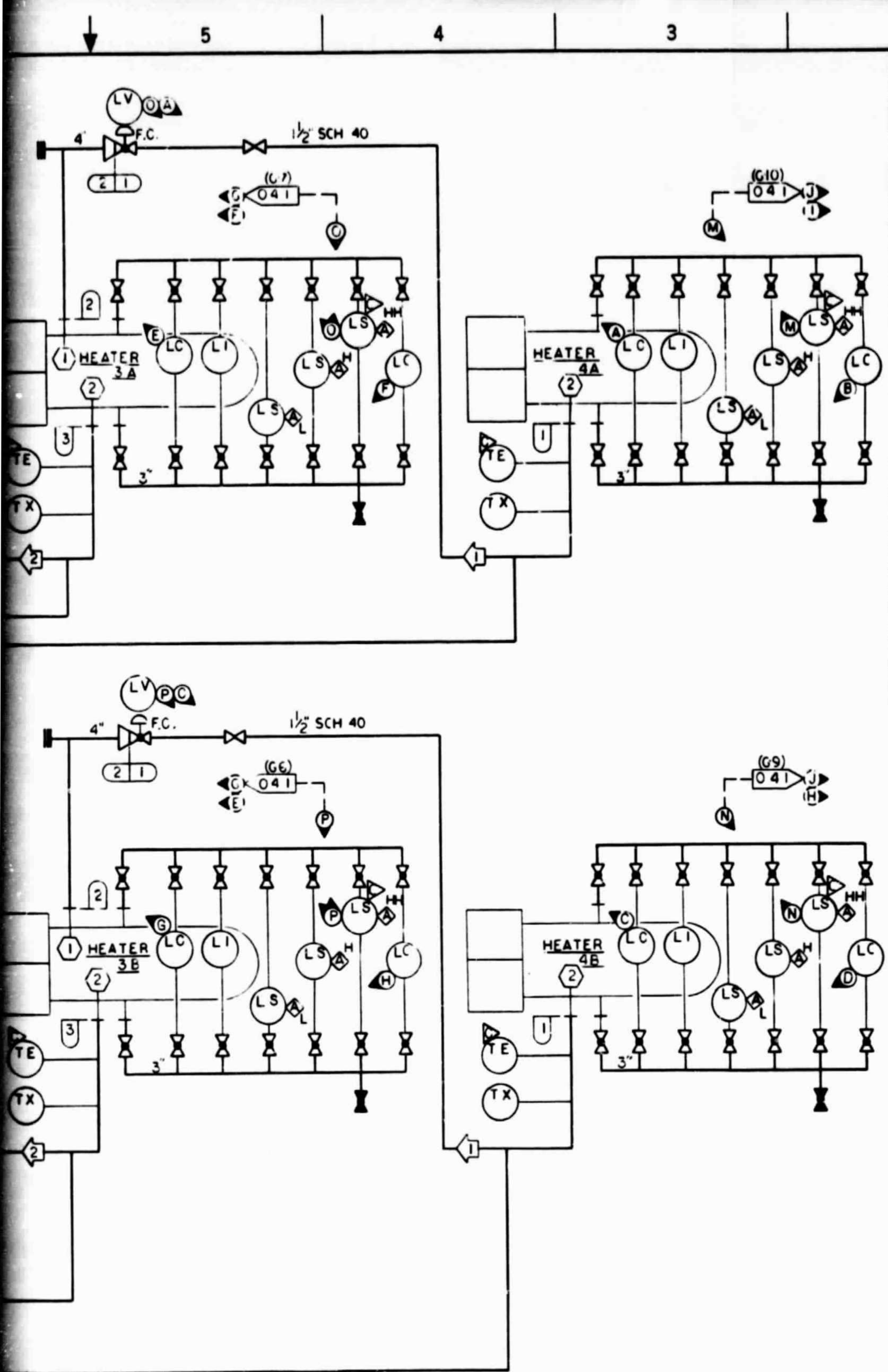
DEAERATOR
DEAERATOR STORAGE TANK
4" SCH 40
14" XS
2 1/2" SCH 40
LP FLASH TANK
HEATER 2A
HEATER 2B
2" SCH 40
4"
3"
F.C.
F.O.
(G 5)
(G-3)
041
101
181
(A-8)
(A-7)
SAMPLING
LV
LS
LC
LI
TE
TX
AE
HH
CONDENSER
SCH 80
2" SCH 40
1 1/2" SCH 40
2 1/2" SCH 40
FOLDOUT FRAME



OPERATING DATA

	FLOW $lb/HR \times 10^3$	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	27	423	414		HTRS 4A&B TO 3A&B	
2	46	260	374		HTRS 3A&B TO 2A&B	
3	72	156	315		HTRS 2A&B TO F/T	
4	27	1	414		HTRS 4A&B TO COND	
5	46	1	374		HTRS 3A&B TO COND	
6	72	1	315		HTRS 2A&B TO COND	
7	129	1	215		F/T TO COND.	
8	15	1	215		F/T TO DEAERATOR	

DESIGN DATA

	FLOW $lb/HR \times 10^3$	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	29	450	420		A 106, GR-C	
2	29	290	420		A 106, GR-C	
3	49	290	380		A 106, GR-C	
4	49	180	380		A 106, GR-C	
5	76	180	320		A 106, GR-C	
6	76	50	220		A 106, GR-C	
7	136	50	220		A 106, GR-C	
8	136/29	50	420/220		A 106, GR-C	
9	16	50	220		A 106, GR-C	

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I.D. NO. C-373-017

DATE	RELEASED FOR	ENGR.
3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	

REV	BY	CHKD	APP	DATE	REVISIONS
1	NI	PES		8-10-81	ADDED H RIGO, DATE & SDD NO. IN TITLE BLOCK

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

FEEDWATER HEATER DRIPS SDD-111

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO

DATE 9-25-81

Gilbert Commonwealth Companies

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING: MADE D.L.H. CHECKED R.S.

ENGINEERING INTERFACES

ENGINEER APPROVAL DEPT. DATE 3/26/81

SCALE NTS

W.O. 008270-001

DRAWING NUMBER 8270-1-525-302-111

REV 1

SYSTEM DESIGN DESCRIPTION

SDD-113

FEEDWATER HEATER AND MISCELLANEOUS DRAINS, VENTS & RELIEFS

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAMS NO. 8270-1-525-302-113 AND 8270-1-519-302-121

George M. Slivka 3/6/81
SYSTEM ENGINEER DATE

Larry L. Wagner 3/17/81
Harry G. Ulanda 3/17/81
REVIEWED DATE

3/18/81
APPROVED DATE

Revision: 1
Date: September 25, 1981
Approved:

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FEEDWATER HEATER AND MISCELLANEOUS DRAINS, VENTS & RELIEFS

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Feedwater Heater Vents, Drains, and Reliefs System and the Miscellaneous Drains System as depicted on Fluid System Diagrams 8270-1-525-302-113 and 8270-1-519-302-121. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

1.1.1 The Feedwater Heater Vents, Drains and Reliefs System is designed to provide draining and venting of the feedwater heaters to the main condenser through piping and valves from the following points.

1. Main Deaerator
2. Feedwater Heaters 2A and 2B
3. Feedwater Heaters 3A and 3B
4. Feedwater Heaters 4A and 4B

1.1.2 The Miscellaneous Drains System is designed to convey condensed steam (condensate) drains through piping and valves to the main condenser from the following points:

1. High Pressure (HP) Turbine Main Steam (2 lines)
2. HP Turbine Exhaust (2 lines)
3. Cold Reheat (1 line)
4. Extraction Steam to Feedwater Heaters 4A and 4B (2 lines)
5. Hot Reheat Steam to Intermediate Pressure (IP) Turbine (2 lines)
6. Extraction Steam to Feedwater Heaters 3A and 3B (1 header, 2 branches)
7. Extraction Steam to Feedwater Heaters 2A and 2B (1 header, 2 branches)
8. Intermediate Pressure (IP) to Low Pressure (LP) Cross-Over
9. Deaerator Extraction Steam (1 line)
10. Hot Reheat Steam to Boiler Feed Pump Turbines "B" and "C" (1 each line)
11. Hot Reheat Steam to Oxidant Turbine (1 line)
12. Hot Reheat Steam to Air Separation Unit (ASU) Turbine (1 line)

1.2 SYSTEM INTERFACES

Major equipment components involved with the Feedwater Heater Vents, Drains and Reliefs System and the Miscellaneous Drains System include the HP, IP and LP turbines; Boiler Feedwater Pump (BFP) turbines "B" and "C"; the two Oxidant turbines; the ASU turbine; the Feedwater Heaters Nos. 2A, 2B, 3A, 3B, 4A, and 4B; and the Main Deaerator. These components are described in the System Design Descriptions which interface with Miscellaneous Drains, namely Main and Reheat Steam, Condensate, and Extraction Steam.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures, temperatures, and pipe sizing flow rates are taken from the plant heat and flow balance diagram and tabulated on the fluid system diagrams 8270-1-525-302-113 and 8270-1-519-302-121. Flow rates are those occurring during turbine startup with the Heat Recovery/Seed Recovery (HR/SR) steam outlet at 20 percent Maximum Continuous Rating conditions. Drain pipe sizing is based on pressure drop and/or condensate velocity in the piping. Condensate velocity is limited to 6 feet per second.

All manifolds consist of drains which are grouped at approximately the same operating pressure.

All drains and manifold connections at the condenser, are located above the hotwell level.

Drain lines from high pressure sources are sized to ensure adequate flow area for volume increases following a critical pressure drop through the drain valve.

The cross sectional area of each drain manifold is ten times the combined area of all drains connecting to the manifold.

Locked open isolation valves are provided for maintenance of all drain valves.

2.0 DESIGN DESCRIPTION

The Feedwater Heater Vents, Drains and Reliefs System and the Miscellaneous Drains System consist of piping, valves and controls. The major equipment components are covered in System Design Descriptions noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

This System Design Description describes drains, vents, and reliefs from the Feedwater Heaters; the main and reheat steam system; and the extraction steam system. Drains are provided at low points in the piping systems for removal of condensate and the warmup and startup periods. Vents are provided at high points in the feedwater heater system to remove noncondensibles. Reliefs are provided on feedwater heater shells and channels to protect against over pressure.

2.1.1 Feedwater Heater Vents, Drains, and Reliefs System

The feedwater heater shells are vented to the main condenser. Each feedwater heater has five separate vent lines; each line is equipped with an orifice plate and an isolation valve. The vent lines are connected to a common header which is piped to the main condenser. A bypass line is installed around one orifice plate at each end of the shell, to be used during startup.

The feedwater heater channel vents are double valved, and open to the atmosphere at the feedwater heater. The shell safety relief valve discharges are piped through the building roof. Safe valve connectors are mounted on the discharge of each valve.

The main deaerator has four separate vent lines. Each vent line is equipped with an orifice plate, an isolation valve and a bypass around each orifice plate and valve. These vent lines are connected to a common header, equipped with a three way control valve which is actuated by a pressure switch mounted on the main deaerator. During startup, the valve is open to the main condenser. During normal operation, the valve is open to the atmosphere, via piping through the building roof.

Two safety relief valves mounted on the deaerator are piped through the building roof. Each safety relief valve has a safety valve connector at the valve discharge.

The vent manifolds of feedwater heaters 4A and 4B are combined into one common line and routed to the high pressure end of the main condenser inlet manifold.

The vent manifolds of feedwater heaters 3A and 3B are combined into one common line and piped to the main condenser inlet manifold.

The vent manifolds from feedwater heaters 2A and 2B are combined into one line and piped to the low pressure end of the main condenser inlet manifold.

2.1.2 Miscellaneous Drains

Miscellaneous drains are as follows:

1. Main Steam Drains

These drains are provided with motor operated valves which are automatically opened on turbine loads below 20 percent. The set point is adjustable. All main steam drains must be operable during startup and shutdown operation below 20 percent load.

2. Drains Upstream of Main Steam Control Valves

These drain lines have motor operated valves provided by the turbine manufacturer. The valves are operated from the main control room for warmup during the turbine startup sequence. These drains are equipped with a stop valve upstream of the main steam control valve. Operation of these valves is outlined in the SDD covering the turbine generator.

3. High Pressure Turbine Casing Drains

These drains have motor operated valves which are operated from the main control room. The valves should be opened during startup and shutdown when the high pressure turbine casing temperature is below 600°F. The valves should be closed when the high pressure turbine casing temperature is above 600°F.

4. Cold Reheat and Heater Lines 4A and 4B

These drains originate at drain pots in the cold reheat line and the extraction lines to heaters 4A and 4B. The discharge from each drain pot is routed through a motor-operated drain valve to a common line and then to the main condenser drain manifold. The drain valves are open during startup.

5. Hot Reheat Drains

These drains are provided with motor operated drain valves which are automatically opened at turbine loads below 30 percent. The set point is adjustable.

6. Reheat Control Valves Upstream Drains

These drains have motor operated valves provided by the turbine manufacturer. The valves are manually operated from the control room. The valves should be opened during startup and shutdown.

The drains from the hot reheat and the reheat control valves are combined into a single line and conveyed to the main condenser manifold through an isolation valve, which is locked open during normal operation.

7. Extraction Drains From Heaters 3A and B, 2A and B

These drains originate at a drain pot in the extraction piping and terminate at the main condenser drain manifold. The discharge of each drain pot is controlled by a motor-operated drain valve. The drain from the extraction header is piped directly to the condenser drain manifold; the heater branches, however, have the drain lines combined into a common line which is routed to the main condenser drain manifold.

8. I.D. to L.P. Cross-Over

The I.P. to L.P. cross-over drains are routed from a drain pot in the cross-over line through a motor-operated drain valve to the main condenser drain manifold.

9. Extraction Drains from the IP and LP Turbines

These drains are routed directly to the main condenser drain manifold through a motor-operated drain valve.

10. Hot Reheat Drains from Boiler Feed Pump Turbines B and C

Hot reheat drains upstream of both the control valve and stop valve of BFP turbines B and C are routed through motor operated drain valves to the main condenser manifold. These valves are automatically opened at turbine loads below 20 percent. The set point is adjustable.

11. Hot Reheat Drains from the Oxidant and Air Separation Unit Turbines

Drains from upstream of the turbine stop and control valves are conveyed to their respective drain manifolds through motor operated drain valves. The drain valves are preset to open automatically at turbine loads below 20 percent. The set point is adjustable.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment components shown on the Feedwater Heater Vents, Drains and Reliefs System and the Miscellaneous Drains System diagrams are the main turbine (HP, IP and LP casings); oxidant turbines; ASU turbine; the BFP turbines B and C; the Feedwater heaters 2A, 2B, 3A, 3B, 4A and 4B; and the Main Cycle Deaerator. These items are described in the following system design descriptions:

Item	System Design Description	Fluid System Diagram
Main Turbine	Main and Reheat Steam System	8270-1-511-302-011
Oxidant Turbine	Oxidant Supply	
ASU Turbine	Oxidant Supply	
BFP Turbines	Boiler Feedwater System	8270-1-521-302-081
Feedwater Heaters	Boiler Feedwater	8270-1-521-302-081
Main Cycle Deaerator	Condensate	8270-1-511-302-101

2.2.2 Piping and Valves

2.2.2.1 Piping

Drain piping from the LP turbine extraction lines is ASTM A106 Grade C carbon steel. The main condenser drain manifold for that pressure level is also A106 Grade C carbon steel pipe.

All other drain piping is ASTM A335 Grade P22 chrome molybdenum steel.

Piping conforms to ANSI B31.1.

2.2.2.2 Valves

Valves are carbon steel or alloy steel as required to conform to the piping in which they are installed.

Motor operated shutoff valves are provided in the main turbine, main steam and reheat steam line drains by the turbine manufacturer.

Motor operated shutoff valves are also installed in the hot reheat drain lines from the Oxidant, ASU and BFP turbines.

All other main turbine drain lines have motor-operated shutoff valves installed in them.

2.2.3 Electrical

Motor-operated valves are 460 volt, 3 phase, 60 Hz, with power supplied from the 480 volt motor control centers.

2.2.4 Instruments, Controls and Alarms

The instruments and controls associated with the drains system include the following:

1. Local pressure indicators are located on each drain manifold.

2. Position indicating lights are located in the main control room for all automatic drain valves. This is accomplished with limit switches mounted on each valve, which indicate fully open and fully closed position.

3. Main and Reheat Steam drain pot level switches, are shown on Fluid System Diagram 8270-1-501-302-011.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits and protective devices will be described and included in System Design Descriptions noted in Section 1.2.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

No special hazards are considered to exist in the Feedwater Heater Vents, Drains and Reliefs System. All safety valves are piped to atmosphere (external to building enclosure) for personnel protection. Drains and channel reliefs are piped to floor drains. Channel vents must be opened with caution, since these are open to atmosphere at the heater area.

No special personnel hazards are considered to exist in the Miscellaneous Drains System beyond those normally observed in conjunction with high temperature and high pressure piping.

4.0 MODES OF OPERATION

4.1 STARTUP

During plant startup, when venting and draining requirements are greatest, the orifice bypasses at each end of each feedwater heater are manually opened. All heater flushing drain valves are closed. Channel vents are cracked open to remove non-condensibles, then closed. The main deaerator vents are open to the main condenser through the pneumatic three-way valve, which is positioned from a main deaerator pressure switch.

All automatic drain valves must be set in the "Open" position and remain in the "Open" position until plant load reaches at least 20 percent, to comply with turbine manufacturer's recommendations. At 20 percent load (increasing) the drain valves are set for automatic operation by the main control room operator.

4.2 NORMAL OPERATION

During normal operation, venting from each feedwater heater flows through the restriction orifices with all bypasses closed. Main Deaerator vents are open to atmosphere through the three-way valve in the manifold line.

The Miscellaneous Drains System is fully automated above 15 percent plant load, for normal operation and for normal load changing.

4.3 SHUTDOWN

During normal shutdown, the venting equipment arrangement is the same as for normal operation. When the heaters are isolated for maintenance, shell and tube sides can be drained through the valves provided.

In a normal, controlled shutdown the steam drain valves are opened at 15 percent load on the steam turbine generator. No other operator action is required.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Monitoring of the position indicating lights located in the main control room should be performed periodically during normal operation to alert to any malfunction.

5.2 INSERVICE INSPECTION

All piping, valves, controls, gauges, pipe supports, etc., shall be inspected during system operation to verify that the equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Piping shall be monitored for wall thickness, on a yearly basis, in selected areas where erosion and/or corrosion may occur. These areas will most likely be directly downstream of the automatic drain valves and the motor operated valves.

All valve stems should be greased on a routine, periodic basis. Each valve in the system should be opened and closed during plant maintenance shutdowns. Valve packing should be inspected yearly and maintained in proper condition.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FEEDWATER HEATER AND MISCELLANEOUS DRAINS, VENTS AND RELIEFS
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Feedwater Heater Vents, Drains and Reliefs	8270-1-525-302-113
Miscellaneous Drains and Vents	8270-1-519-302-121

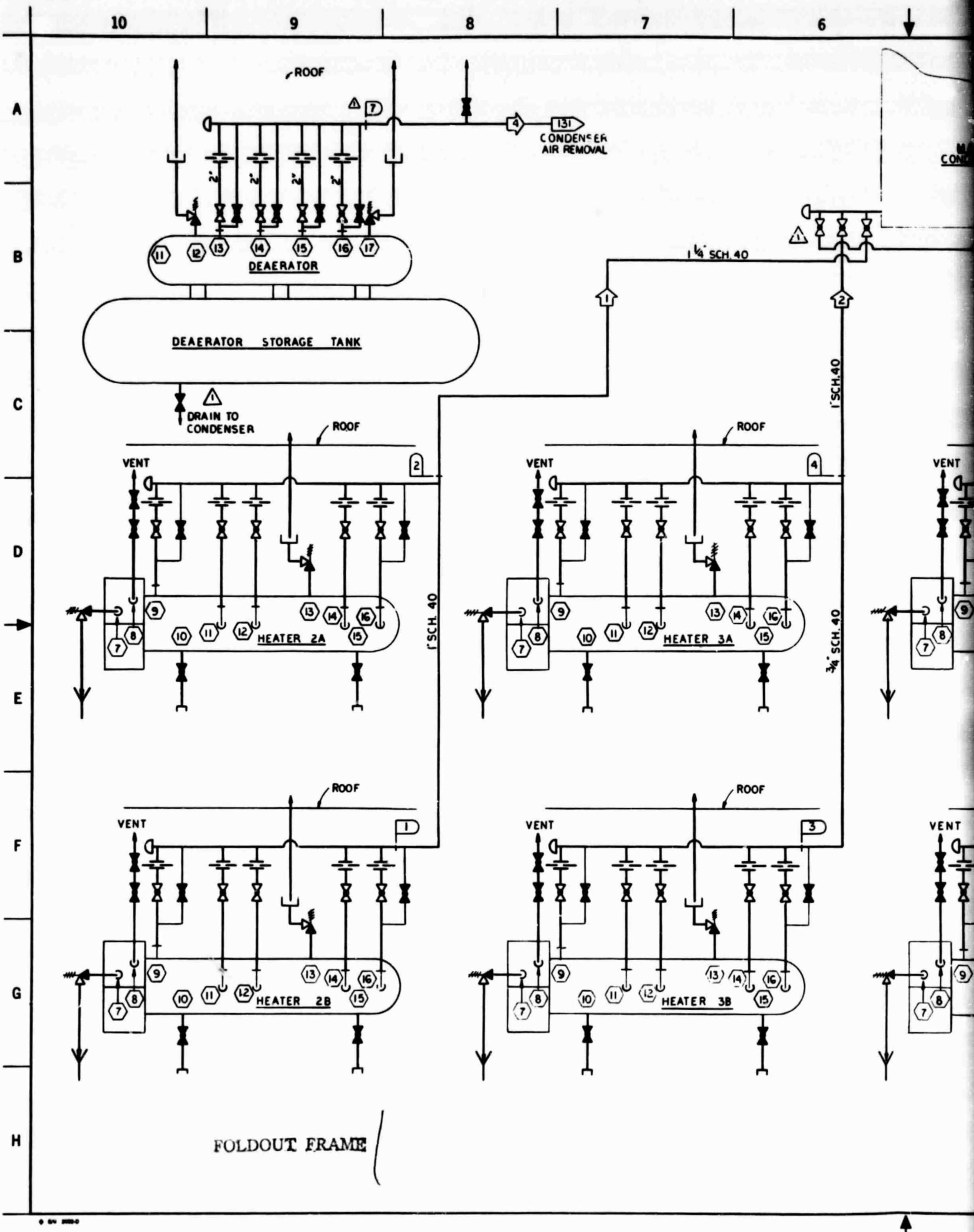
REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Main & Reheat Steam
Condensate
Extraction Steam

Plant Heat & Flow Balance Diagram

System Heat Balance	8270-1-540-314-001



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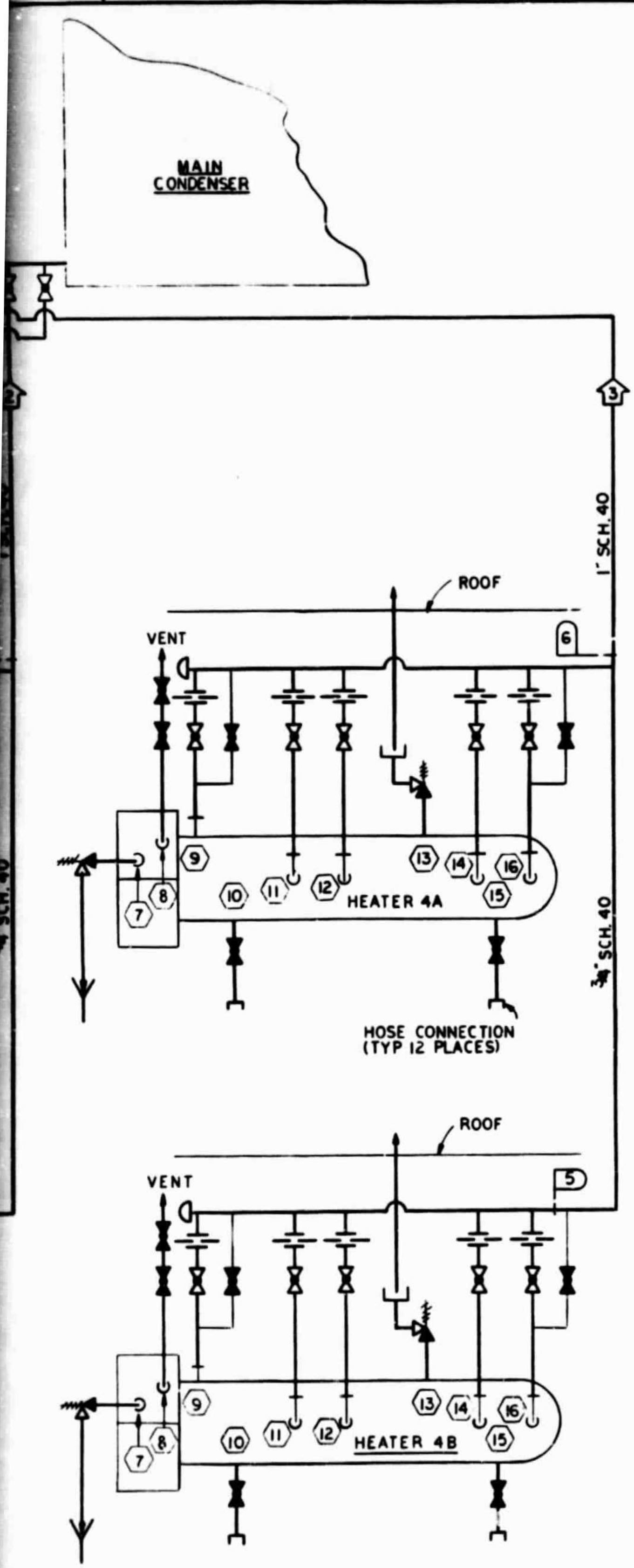
131
CONDENSER
AIR REMOVAL
2"
DEAERATOR
DEAERATOR STORAGE TANK
DRAIN TO
CONDENSER
1 1/4" SCH. 40
1" SCH.40
3/4" SCH. 40
1" SCH. 40
VENT
HEATER 2A
HEATER 3A
HEATER 2B
HEATER 3B
FOLDOUT FRAME



OPERATING DATA

#	FLOW LB/HR	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	260	50	369		HTRS. 2A&2B VENT	
2	192	50	409		HTRS. 3A&3B VENT	
3	272	50	454		HTRS 4A&4B VENT	
4	417	1	310		DEAERATOR VENT	

DESIGN DATA

#	FLOW LB HR	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	140	175	375		A106 GRADE B	
2	275	175	375		A106 GRADE B	
3	105	300	420		A106 GRADE B	
4	210	300	420		A106 GRADE B	
5	150	450	460		A106 GRADE B	
6	285	450	460		A106 GRADE B	
7	440	50	315		A106 GRADE B	

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2-13-81	PRELIMINARY ISSUE	
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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

FEEDWATER HEATER VENTS, DRAINS & RELIEF VALVES SDD-113

200 MWe

DOE – NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO

DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING | ENGINEERING INTERFACES

SCALE NTS

8270-1-525-302-113 | REV 1

DRAWING NUMBER

REVISIONS

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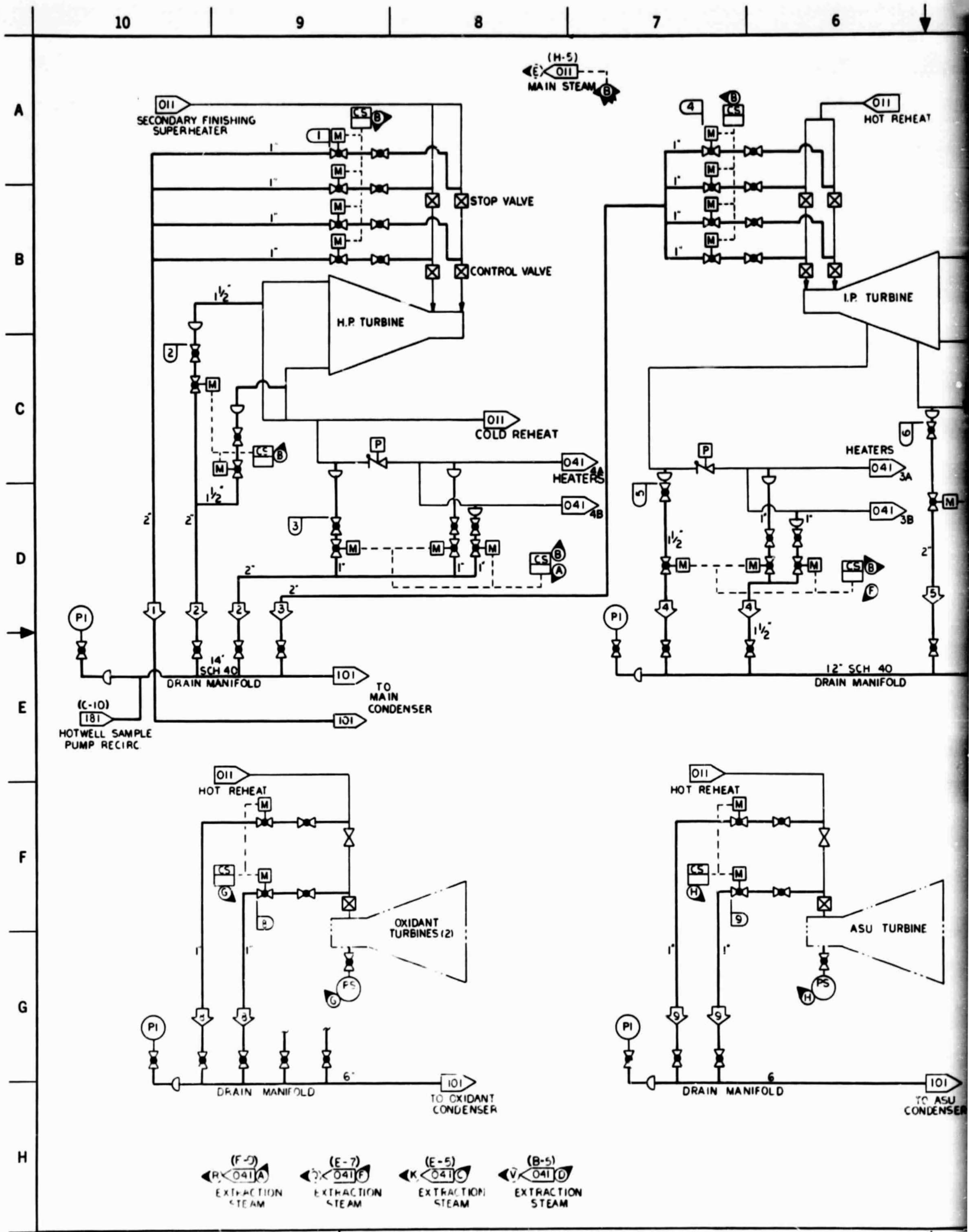

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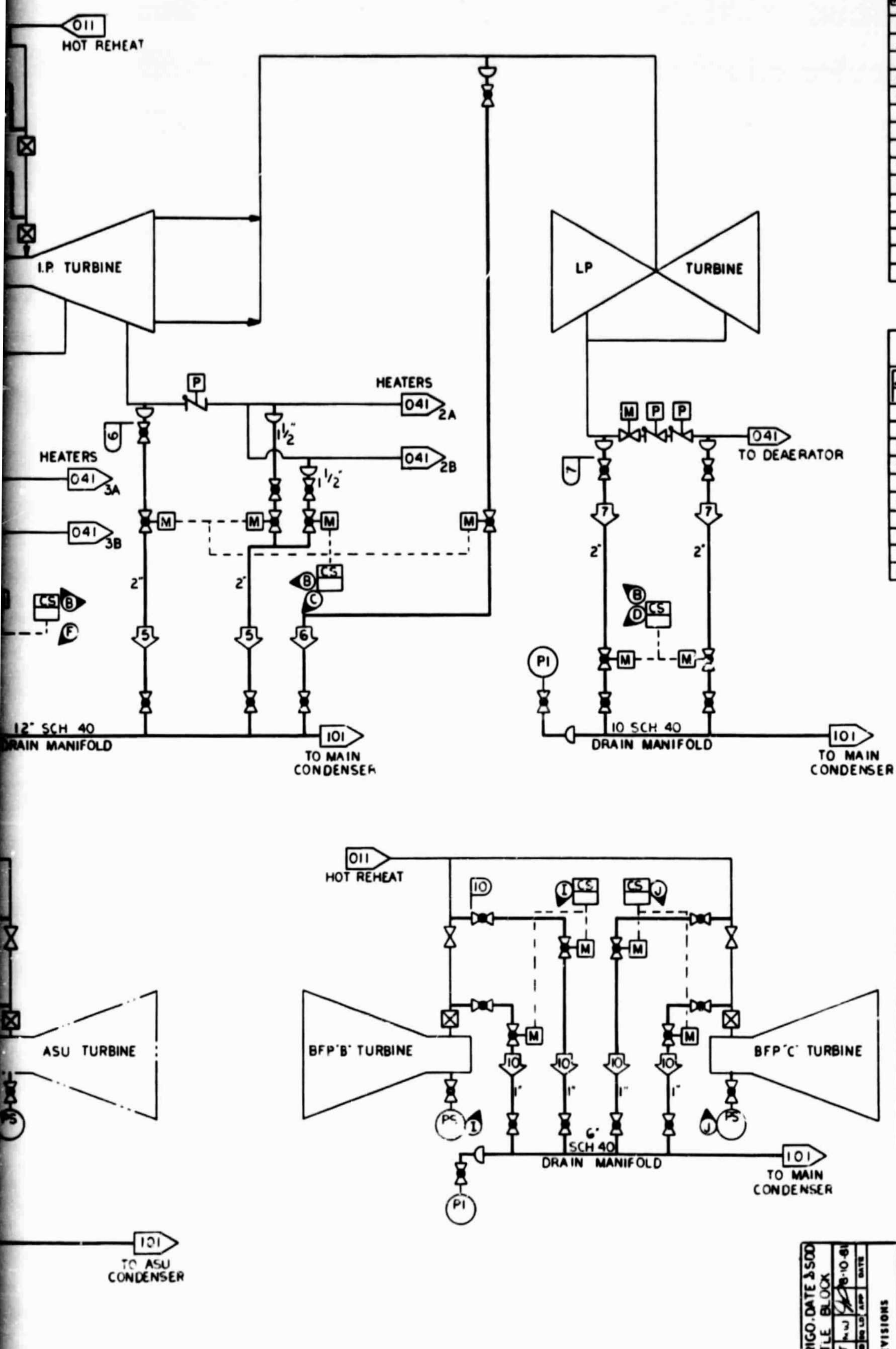

OPERATING DATA

#	FLOW LB/HR	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	TBD	TBD	TBD		HP TURB. STEAM DRN.	
2	TBD	TBD	TBD		HP TURB. EXH. DRN.	
3	TBD	TBD	TBD		IP TURB. STEAM DRN.	
4	TBD	TBD	TBD		IP TURB. EXH. DRN.	
5	TBD	TBD	TBD		IP TURB. EXH. DRN.	
6	TBD	TBD	TBD		IP TO LP CROSSOVER DRN	
7	TBD	TBD	TBD		L.P. TURB. EXH. DRN.	
8	TBD	TBD	TBD		OXIDANT TURB. STM. DRN	
9	TBD	TBD	TBD		ASU TURB. STEAM DRN.	
10	TBD	TBD	TBD		BFP TURB. STEAM DRN.	

DESIGN DATA

#	FLOW LB/HR	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	TBD	2070	1005		A335 GR P22	
2	TBD	540	655		A335 GR P22	
3	TBD	540	655		A335 GR P22	
4	TBD	500	1005		A335 GR P22	
5	TBD	300	950		A335 GR P22	
6	TBD	175	900		A335 GR P22	
7	TBD	50	325		A106 GR B	
8	TBD	2070	1005		A335 GR P22	
9	TBD	2070	1005		A335 GR P22	
10	TBD	2070	1005		A335 GR P22	

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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM
MISCELLANEOUS DRAINS AND VENTS SDD-113
200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPR. H. RIGO
DATE 9-25-81

Gilbert Commonwealth Companies
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING — ENGINEERING INTERFACES
MADE ALK — CHECKED
ENGINEER APPROVAL — M.E. — 3/26/81 — DEPT. — DATE
SCALE NONE
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8270-1-519-302-121 — DRAWING NUMBER
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REVISIONS

REV	MADE	CHKD	ENG	APP	DATE	
1	NL				8-10-81	ADDED H. RIGO, DATE & SDD NO. IN TITLE BLOCK

SYSTEM DESIGN DESCRIPTION

SDD - 131

CONDENSER AIR REMOVAL SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-491-302-131

Jermel Shim 2/12/81

SYSTEM ENGINEER DATE

T C Reitz 3/17/81

Harry G Hosler 3/17/81

REVIEWED DATE

JW Phillips 3/18/81

APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved: JW Phillips

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CONDENSER AIR REMOVAL SYSTEM

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Condenser Air Removal System as depicted on Fluid System Diagram 8270-1-491-302-131, Condenser Air Removal. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Condenser Air Removal System is designed to remove air and any other noncondensable gases from the main condenser, Oxidant compressor condensers and Air Separation Unit (ASU) compressor condenser.

Two rotary vacuum pumps and a steam jet air ejector (SJAE) are provided to remove the noncondensable gases from the surface condensers and discharge them to atmosphere.

1.2 SYSTEM INTERFACES

Major equipment components involved with the Condenser Air Removal System include the Main condenser, two Oxidant compressor condensers, ASU compressor condenser, SJAE (with auxiliaries), and two vacuum pumps (with auxiliaries).

The Condenser Air Removal System interfaces with the Main and Reheat Steam System and the Condensate System. These systems are described in their respective system descriptions.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components. Air ejection rates have been determined in accordance with criteria established by the Heat Exchange Institute (HEI).

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)
6. Pipe Fabricators Institute (PFI)

7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (HFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

Noncondensable flow rates from the condensers are based on the quantities of steam condensed. These values are taken from the Sixth Edition of HEI Standards for Surface Condensers and are used to determine pipe sizes and to select equipment.

2.0 DESIGN DESCRIPTION

The Condenser Air Removal System consists of two rotary vacuum pumps, steam jet air ejector, silencer, piping, valves and instrumentation.

2.1 SUMMARY DESCRIPTION

The Condenser Air Removal System utilizes two half capacity rotary vacuum pumps and a steam jet air ejector to remove noncondensable gases and air from the steam space of the four surface condensers.

The surface condensers are 2-pass with divided waterboxes. Each condenser half has its own air removal line which includes an isolation butterfly valve. The air removal lines are piped to a common line which goes to a header. From the header, separate lines are piped to the rotary vacuum pumps and the steam jet air ejector.

The SJAE is a single element two stage type; equipped with intercondensers and after condensers. It is used as a backup for holding vacuum in the event of local power failure. Cycle steam is admitted to the ejector where the noncondensable gases and air are mixed to entrain the gases in the steam jet. The mixture then passes through the intercondenser where the steam is condensed to a second stage. The second stage ejector discharges the mixture into the aftercooler where the steam is condensed before the noncondensables are discharged to atmosphere.

Condensate drains from the intercooler and the aftercooler are returned to the main condenser hotwell. The aftercooler drain line is fitted with an automatic trap and the common drain line to the condenser is designed with a loop-seal arrangement to permit proper drainage.

Each rotary vacuum pump is part of an equipment package which includes an automatically controlled air ejector that operates when the system vacuum is very high. The air ejector uses air as the motive fluid to entrain the noncondensables, and operates as a hogger during startup or to rapidly reduce high pressure in the condensers. At lower vacuums, the air ejector is bypassed automatically and the rotary vacuum pump, pumps directly from the condensers. A 3-port control valve shuts off air to the air ejector and opens the bypass control valve when the vacuum reaches a predetermined level.

One rotary vacuum pump is normally operated and the other maintained for standby. A decrease in the set level of system vacuum will automatically start the standby pump. Both pumps will continue to operate until the standby is manually turned off from the control room.

The rotary vacuum pumps are of the liquid ring type. Sealing liquid (water) is part of a closed loop consisting of a heat exchanger, separator, and a circulating water pump.

Each vacuum pump package has its own air/water separator. The discharge from each pump is piped to the separator which removes the moisture from the noncondensable gases, and discharges the air to atmosphere via a silencer.

Seal water for priming the rotary vacuum pumps is provided by the liquid collected in the separator. A recirculation centrifugal pump, pumps the liquid through a heat exchanger before it enters the vacuum pump. Condensate from the condensate system is used for makeup and as the cooling medium. To ensure that an adequate amount of liquid is in the separator, a float control valve is provided in the vacuum pump separator to control the makeup water flow. During operation of the vacuum pump, water vapor from the condenser that is condensed within the exhauster provides continuous makeup to the system. To remove excess water a line is piped from the separator to waste. This excess flow is controlled by a float control valve on the separator.

A rotometer is provided on the rotary vacuum pumps for air leakage measurement. Silencers are provided at the discharge of the vacuum pumps for noise suppression. The rotary vacuum pumps discharge to atmosphere above the turbine room roof.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 Steam Jet Air Ejector

Quantity	1
No. of elements	1
No. of stages	2
Max. Steam Inlet Temperature	620°F
Max. Steam Inlet Pressure	235 psig
Design Capacity (Dry air leakage removal)	27.5 scfm

2.2.1.2 Rotary Vacuum Pumps

Quantity	2
Type	Rotary Vane, Liquid Sealed
Design Capacity (Dry air leakage removal)	30 scfm
Holding Capacity	50 scfm @ 2.5" HgA
Motor hp	150 hp
Speed	1850 rpm

2.2.2 Piping and Valves

The Condenser Air Removal System piping is designed with welded joints in accordance with ANSI B31.1. Piping is ASTM A106, Grade B or ASTM A53 Grade B seamless carbon steel.

Manually operated butterfly valves are provided on the air offtake of each surface condenser half. Diaphragm operated butterfly valves are provided on the inlet line to the rotary vacuum pumps and the SJAE.

Air removal lines to the steam ejector and the vacuum pumps contain isolation gate valves and control valves.

Valve materials are compatible with pipe materials.

2.2.3 Electrical

Each vacuum pump motor is provided with a NEMA size 5 starter. The starters will be located in a motor control center (MCC) near the motors. The MCC will be fed from a 480 volt switchgear breaker located in a load center.

2.2.4 Instruments, Controls and Alarms

The Condenser Air Removal System is provided with appropriate locally installed instrumentation for sensing flow, pressure, level and temperature.

The vacuum pumps are monitored and controlled from the main control room. After starting, a pump will function automatically as the vacuum conditions change.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

No major personnel hazards are considered to exist in the Condenser Air Removal System. However, plant personnel must be aware of high temperature lines to the steam ejector and observe safety precautions normally required for electrical motors.

3.3 PRECAUTIONS

Before starting the rotary vacuum pump, a check should be made to ensure that the recirculation pump is running and delivering sealing liquid to the vacuum pump. Starting the vacuum pump without liquid in the casing will result in serious damage.

4.0 MODES OF OPERATION

4.1 STARTUP

The Condenser Air Removal System is started after adequate gland steam sealing pressure is established to the turbines. The startup procedure is briefly as follows:

1. All isolating gate and butterfly valves on the air removal lines from the condensers to the rotary vacuum pumps are opened.

2. Condensate flow is established thorugh the sealing liquid heat exchanger.

3. Recirculation pump is started from the main control.

4. One rotary vacuum pump is started from the main control room.

Operation of the rotary vacuum pump is completely automatic once started. During startup or when condenser pressure is very high the atmospheric air ejector operates in series with the rotary vacuum pump. When the inlet pressure is reduced to condenser design conditions, the air ejector is bypassed and the rotary vacuum pump operates on its own to hold vacuum at an optimum level.

The procedures for starting the SJAE are as follows:

1. Confirm condensate is flowing through the intercondenser and the aftercondenser.

2. Open LT Reheat steam control valve to allow steam to the SJAE.

3. Open isolating control valve on air removal line to the SJAE.

4. Close isolating valves for rotary vacuum pumps.

4.2 NORMAL OPERATION

Normal operation of the Condenser Air Removal System is achieved when one vacuum pump is able to hold system vacuum at the desired optimum level.

4.3 SHUTDOWN

The Condenser Air Removal System is in continuous operation when the plant is operating and will only be shutdown in conjunction with a plant shutdown.

To shutdown a rotary vacuum pump or the SJAE, the startup procedure under Section 4.1 is reversed.

4.4 SPECIAL OR INFREQUENT OPERATION

Operation of the SJAE will be infrequent. No special or infrequent operation of any other equipment in the Condenser Air Removal System is anticipated.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Air leakage into the condensers will be measured by the rotometer provided on each separator, and by a metering orifice and manometer when the steam ejector is in operation.

Operating personnel will record these measurements at regular intervals and use them to determine if there is excessive air leakage into the condensers.

5.2 INSERVICE INSPECTION

During Condenser Air Removal System operation, regular checks must be made to ensure that all equipment and components are operating properly. These checks will be in accordance with the manufacturer's instructions and standard operating procedures applicable for the system.

5.3 PREVENTATIVE MAINTENANCE

A preventative maintenance program will be implemented for the Condenser Air Removal System. Normally, any major overhaul and inspection of equipment and components will be carried out during the annual plant shutdown. Other checks and inspection as recommended by the manufacturers will be carried out more frequently.

The preventative maintenance program will also incorporate a lubrication program for the rotary vacuum pumps.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide plant personnel in maintenance and overhaul of any piece of equipment.

5.4.2 Spare Part Inventory

The manufacturer will supply a list of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CONDENSER AIR REMOVAL SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Condenser Air Removal	8270-1-491-302-131

REFERENCE DOCUMENTS - NOT ATTACHED

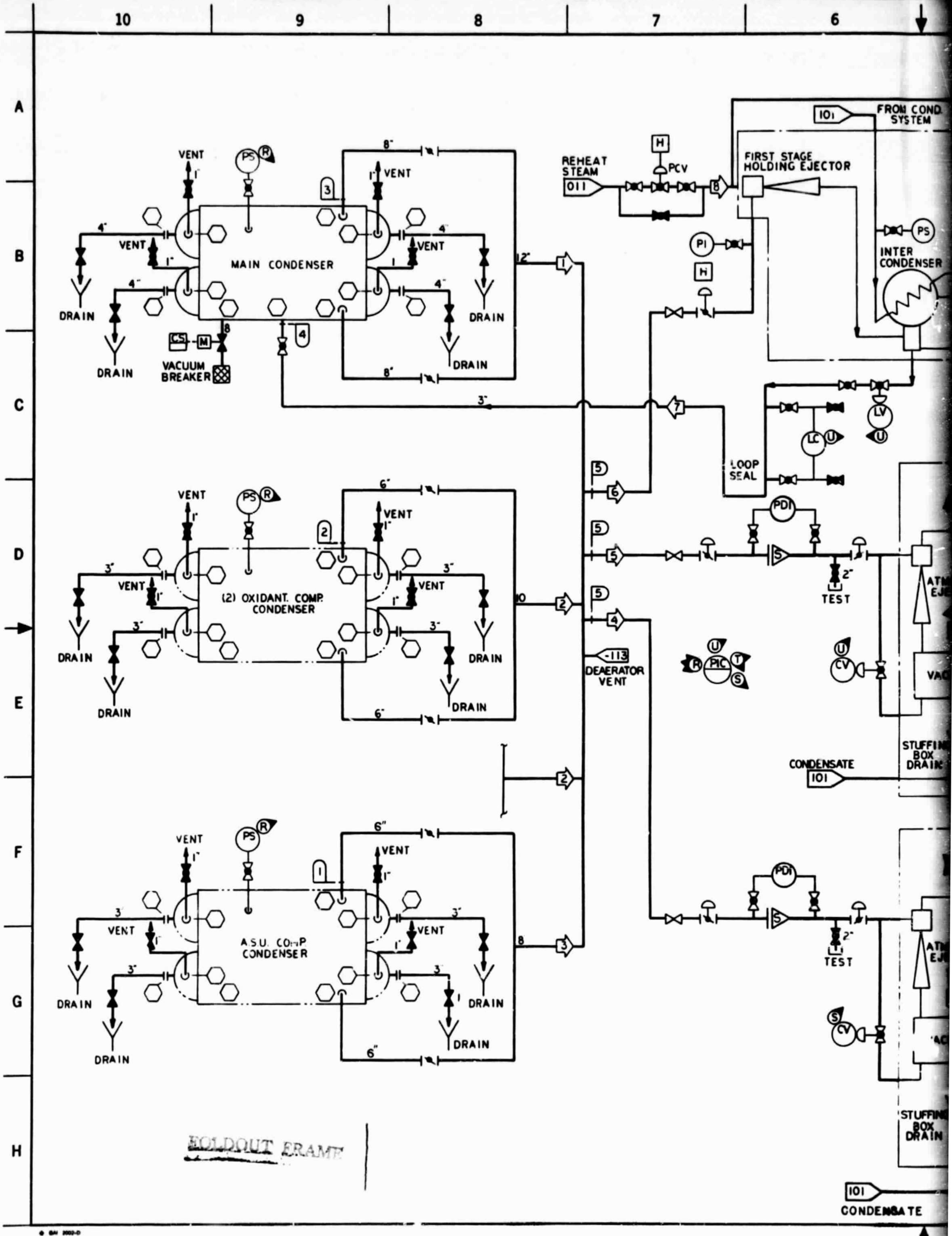
System Design Descriptions

Condensate

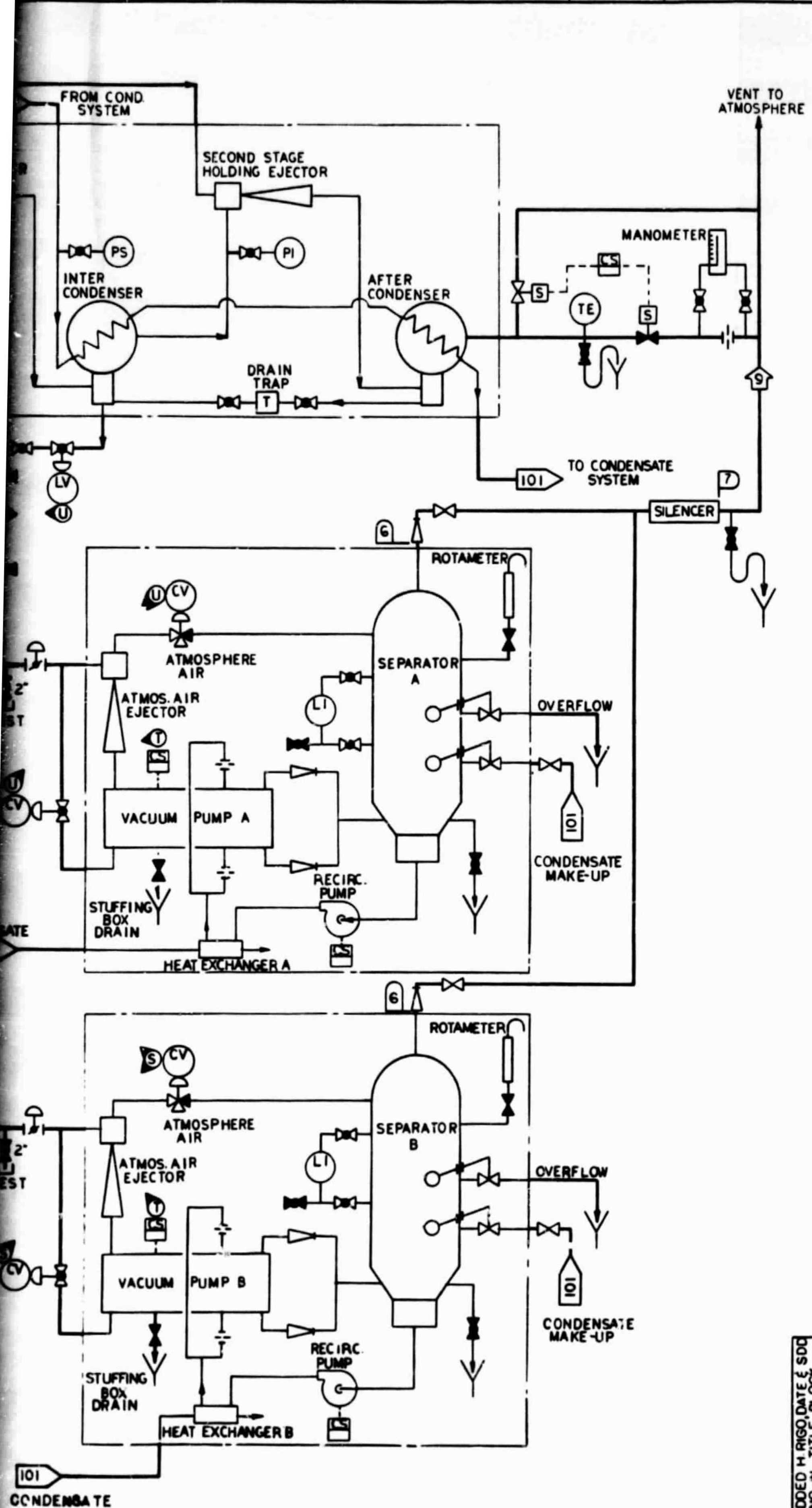
Main and Reheat Steam

Plant Heat & Flow Balance Diagram

System Heat Balance	8270-1-540-314-001



MAIN CONDENSER
VENT
DRAIN
VACUUM BREAKER
(2) OXIDANT. COMP. CONDENSER
A.S.U. COMP CONDENSER
REHEAT STEAM
PCV
FIRST STAGE HOLDING EJECTOR
FROM COND. SYSTEM
INTER CONDENSER
LOOP SEAL
DEAERATOR VENT
TEST
CONDENSATE
STUFFING BOX DRAIN
FOLDOUT FRAME



OPERATING DATA

⇨	FLOW LB/HR	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	180	-12.2	101		MAIN COND AIR LN.	
2	72	-13.5	109		OXDT COND AIR LN.	
3	72	-13.5	109		ASU COND AIR LN.	
4	396	-13.5	107		AIR SUCT. TO PUMP	
5	396	-13.5	107		AIR SUCT. TO PUMP	
6	396	-13.5	107		AIR SUCT. TO SJAE	
7	1000	-13.5	200		DRAIN FROM SJAE	
8	1000	200	649		STEAM TO SJAE	
9	124	14.7	100		VENT TO ATMOS.	

DESIGN DATA

P	FLOW #/HR 10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	38	50	120		A106 GRADE B	
2	38	50	120		A 106 GRADE B	
3	95	50	120		A 106 GRADE B	
4	1050	50	200		A 106 GRADE B	
5	416	50	120		A 106 GRADE B	
6	130	50	120		A 106 GRADE B	
7	130	50	120		A 106 GRADE B	

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FOLDOUT FRAME 2

I.D. NO. C-373-830

3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	
	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEMS DIAGRAM
CONDENSER AIR REMOVAL SDD-131
200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. C. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

SCALE NONE
W.O. 08275-201

8270-1-491-302-131 REV 1

DRAWING NUMBER

REVISIONS

REV				DATE
1	ADDED H. RIGO, DATE & SDD NO. IN TITLE BLOCK	RPJ	NW	8-10-81

Zones: 5 4 3 2 1; A B C D E F G H

SYSTEM DESIGN DESCRIPTION

SDD-161

PLANT MAKEUP WATER SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-582-302-161

J A Bolognese 2/25/81

SYSTEM ENGINEER DATE

T C Reitz

REVIEWED DATE

3/5/81

APPROVED DATE

Revision: 1
Date: September 25, 1981
Approved:

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
PLANT MAKEUP WATER SYSTEM

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Plant Makeup Water System as depicted on Fluid System Diagram 8270-1-582-302-161, Plant Makeup Water. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Plant Makeup Water System is designed to store, transfer and treat (when necessary) the raw water source(s) so that they are suitable as makeup water for the following major plant uses:

1. Cooling tower makeup
2. Cycle makeup
3. Potable water
4. Fire service
5. Miscellaneous plant maintenance requirements such as chimney, air heater and precipitator washes, boiler chemical cleaning and system filling and flushing.

1.2 SYSTEM INTERFACES

Major equipment components involved with the Plant Makeup Water System include the Filtered Water Tank, Raw Water Supply Pumps and Storage Tank, Raw Water Treatment System, Filtered Water Pumps, Raw Water Transfer Pumps, Potable Water Booster Pumps and Hydropneumatic Tank, Makeup Demineralizer and distribution piping to the miscellaneous services and plant uses. The Plant Makeup Water System interfaces with other major systems such as the Circulating Water System, Condensate System and Fire Service. These are described in their respective System Design Descriptions.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow and storage requirements, pressure-temperature ratings and system limits to be used in the selection of required components.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI).
2. American Society of Mechanical Engineers (ASME).
3. American Society for Testing and Materials (ASTM).
4. American Welding Society (AWS).

5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS).
6. Pipe Fabrication Institute (PFI).
7. Occupational Safety and Health Administration (OSHA).
8. Instrument Society of America (ISA).
9. National Fire Protection Association (NFPA).
10. American Water Works Association (AWWA).

1.3.2 Design Parameters

Source water is assumed as well water and/or a raw surface water supply such as a lake or river.

Water storage shall be provided as follows:

1. Filtered Water Storage Tank - two storage sections to include:

    a. Fire protection storage - minimum of two hours at design flow rate. This shall be available for fire service at all times.

    b. Cycle makeup water storage - minimum of 24 hours at design flow rate of one demineralizer train. This storage is in addition to that required for fire protection.

2. Standby Fire Protection Tank - minimum of two hours at design flow rate.

3. Raw Water Storage Tank - minimum of two hours at design cooling tower makeup flow rate.

Cycle makeup demineralizer capacity shall be 3 percent of maximum main steam flow. The demineralizer shall consist of two 1.5 percent trains. The final unit in the train shall be a mixed bed demineralizer.

Channel cooling water shall be condensate 100 percent polished by a mixed bed demineralizer.

Basic treatment of the source water shall produce filtered water quality suitable for makeup to the demineralizer and fire protection system.

2.0 DESIGN DESCRIPTION

The Plant Makeup Water System consists of water storage tanks, pumps, piping, valves and controls. The major equipment components are covered in Section 2.2.

2.1 SUMMARY DESCRIPTION

Makeup water for the plant is assumed as obtainable from a surface sources or wells. If wells cannot supply enough water for cooling tower makeup (2,000 - 4,000 gpm), the alternate supply from a river or lake is required.

Well water is metered and stored in a Filtered Water Tank for use primarily as a supply for a demineralizer which provides makeup to the condensate-feedwater cycle and for fire protection. The upper portion of the storage tank is used as cycle makeup. The lower portion of the tank is available for fire protection only and is piped accordingly to achieve this requirement. A Filtered Water Pump (and a 100 percent spare pump) is provided which draws water from the Filtered Water Tank and pumps it to the makeup demineralizer system and other services which require filtered water.

A separate line from the well water supply is provided for potable water service in the plant. The supply pressure is boosted by a Potable Water Booster Pump (and a 100 percent spare pump). A hydropneumatic surge tank is provided on the pump discharge. The tank is equipped with level controls and uses plant air to maintain the required pressure for the plant potable water system.

The makeup demineralizer system consists of two trains each sized for 1.5 percent of main steam flow. Each train consists of a carbon filter, cation unit, anion unit and mixed bed unit. Regeneration equipment and controls are provided to regenerate cation and anion exchange resins with the use of sulfuric acid and sodium hydroxide. A control panel is provided for pushbutton automatic regeneration. The panel also includes remote manual controls for carbon filter backwash, flow meters, conductivity, pH and silica analyzers and recorders, alarms, timers, pump and valve control switches, and indicating lights.

The Raw Water Storage Tank stores well water (or other source). A Raw Water Transfer Pump (and a 100 percent spare pump) is provided to pump makeup to the cooling tower from the Raw Water Storage Tank. Raw water is piped also to other miscellaneous intermittent requirements such as chimney, air heater and precipitator washing systems.

Alternatively, the system is arranged to treat raw water from another source to produce filtered water for storage in the Filtered Water Tanks. This would supplement and/or replace the requirement for city water. The type of treatment required for raw water will be determined by the water analysis of the wells, river or lake supply.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 Filtered Water Tank

1.	Capacity (Potable, makeup/fire service)	400,000 gal (100,000/300,000)
2.	Design pressure/temperature	Atmos/100°F
3.	Code or standard	AWWA or API
4.	Material	Carbon Steel
5.	Internal coating	Required
6.	Diameter x height	47 x 31 feet

2.2.1.2 Filtered Water Pumps

1.	**Quantity**	**2 (100% each)**
2.	**Type**	**Horizontal-Centrifugal**
3.	**Capacity/total head, each**	**520 gpm/230 ft**
4.	**Motor hp/rpm**	**50/1800**
5.	**Motor volts/phase/hertz**	**460/3/60**

2.2.1.3 Potable Water Booster Pumps

1.	**Number**	**2 (100% each)**
2.	**Type**	**Horizontal-Centrifugal**
3.	**Capacity/total head, each**	**150 gpm/150 ft**
4.	**Motor hp/rpm**	**10/3,600**
5.	**Motor volts/phase/hertz**	**460/3/60**

2.2.1.4 Potable Water Hydropneumatic Tank

1.	**Design pressure/temperature**	**100 psig/100°F**
2.	**Code**	**ASME VIII**
3.	**Material**	**Carbon Steel**
4.	**Internal coating**	**Required**

2.2.1.5 Raw Water Supply Pumps

1.	Number	2 (100% each)
2.	Type	Horizontal-Centrifugal
3.	Capacity/total head, each	4,100 gpm/200 ft
4.	Motor hp/rpm	300/1,800
5.	Motor volts/phase/hertz	460/3/60

2.2.1.6 Raw Water Storage Tank

1.	Capacity	300,000 gal.
2.	Design pressure/temperature	Atmos/100°F
3.	Code or standard	AWWA or API
4.	Material	Carbon Steel
5.	Internal coating	Required
6.	Diameter x height	41 x 31 feet

2.2.1.7 Raw Water Transfer Pumps

1.	Number	2 (100% each)
2.	Type	Horizontal-Centrifugal
3.	Capacity/total head, each	4,100 gpm/230 ft
4.	Motor hp/rpm	350/1,800
5.	Motor volts/phase/hertz	460/3/60

2.2.1.8 **Makeup Demineralizer System**

1. **Carbon filters**

a.	Number	2
b.	Capacity, each	35 gpm
c.	Code	ASME VIII
d.	Media/bed depth	Activated carbon/5 ft.
e.	Mate. ial	Carbon Steel
f.	Internal coating	Heresite or equal

2. Cation Units

a.	Number	2
b.	Capacity, each	35 gpm
c.	Code	ASME VIII
d.	Design pressure/temperature	50 psig/100°F
e.	Type resin	IR-120 or equal
f.	Gallons throughput before exhaustion	49,000 + Regen. Water
g.	Material/internal lining rubber	Carbon Steel/3/16"

3. Anion Units

a.	Number	2
b.	Capacity, each	35 gpm
c.	Code	ASME VIII
d.	Design pressure/temperature	50 psig/100°F
e.	Type resin	IRA-402 or equal
f.	Gallons throughput before exhaustion	49,000 + Regen. Water
g.	Material/internal lining rubber	Carbon Steel/3/16"

4. Mixed Bed Units

a.	Number	2
b.	Capacity, each	35 gpm
c.	Code	ASME VIII
d.	Design pressure/temperature	50 psig/100°F
e.	Type resin cation/anion	IR-120/IRA-402
f.	Gallons throughput before exhaustion	35 gpm for 7 days
g.	Material/internal lining rubber	Carbon Steel/3/16"

5. Acid Storage Tank

a.	Type	Horizontal
b.	Capacity	5000 gal.
c.	Material	1/2" thick carbon steel

6. Acid Regeneration Pumps

a.	Number	2
b.	Materials	Alloy 20
c.	Motor hp	1.5
d.	Motor volts/phase/hertz	460/3/60

7. Caustic Storage Tank

a.	Type	Horizontal
b.	Capacity	5000 gal.
c.	Material	3/8" thick carbon steel

8. Caustic Regeneration Pumps

a.	Number	2
b.	Materials	316 SS
c.	Motor hp	1.5
d.	Motor volts/phase/hertz	460/3/60

9. Control Panel — (to be determined)

2.2.2 Piping and Valves

The piping and valves for the various water services are provided to be suitable for each application as follows:

2.2.2.1 Well Water, Potable Water and Filtered Water*

1.	Below ground	Ductile iron, cement mortar lined, ANSI A21.51.
2.	Above ground	Seamless carbon steel, ASTM A106 Gr. B or A53 Type S, Gr. B or E.

2.2.2.2 Raw Water

1.	Below ground	Reinforced fiberglass pipe, ASTM D1763 or D2310.
2.	Above ground	Seamless carbon steel, ASTM A106 Gr. B or A53 Type S, Gr. B or E.

*2" and under shall be hard drawn copper water tube, ASTM B88, for potable water.

2.2.2.3 **Demineralized Water**

1.	Below ground	Reinforced fiberglass, ASTM D1763 or D2310.
2.	Above ground	Type 304L stainless steel, Sch. 10, ASTM A312.

2.2.2.4 **Piping Pressure and Temperature Ratings**

Piping pressure and temperature ratings will be suitable for the services. It is anticipated these will not exceed 150 psig and 100°F. Pipe joints, fittings and valves will be compatible with the pipe materials.

2.2.3 Electrical

Pump motors are 460 volt, 3 phase, 60 Hz with power supplied from 480 volt motor control centers. Level controls, solenoid valves and other controls will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls and Alarms

The Filtered Water Tank is provided with high and low level switches which give an alarm indication requiring operator action. The low level switch will automatically trip the operating Filtered Water Pump to prevent it from running dry and possibly causing damage to the pump and motor.

Each Filtered Water Pump is provided with a discharge pressure indicator.

Each Potable Water Booster Pump is provided with a discharge pressure indicator.

The Potable Water Hydropneumatic Tank is provided with high and low level and pressure switches to control the Potable Water System supply pressure. High level cuts off the Booster Pump. Low pressure, caused by a drop in tank level, starts the Booster Pump to maintain a predetermined water level range in the tank. If the pressure in the tank falls below the pump start pressure, an air pressure control valve and controller are provided to admit plant air to maintain set pressure within the control limits of the system. Pressure and level switches are provided with alarm contacts to alert the operators in case of malfunction of the pressure control system.

Raw Water Supply Pumps are each provided with a discharge pressure indicator.

The Raw Water Storage Tank is provided with a level control valve and controller to maintain a preset level. A level indicator is also included. A tank low level switch is also provided to alarm and to shut down a Raw Water Transfer Pump when activated. A tank high level switch is provided to shutdown the Raw Water Supply Pump and initiate an alarm when activated.

Raw Water Transfer Pumps are manually operated with one pump normally running to supply cooling tower makeup. Each pump is provided with a discharge pressure indicator.

The makeup demineralizer has its own set of instruments and controls included with the package system. These essentially function to shut down or recycle the demineralized water effluent when poor quality is indicated or when the condensate storage tank level is high. A makeup demineralizer system common alarm is actuated in the main control room to indicate "Makeup Demineralizer Trouble".

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Provisions are included to isolate the well water and potable system from any other plant system to prevent contamination of drinking water. This will be accomplished by an approved backflow preventer or by a suitable design for isolating the well water supply piping at the storage tank.

Level switches are provided at the Filtered Water Tank and Raw Water Storage Tank for low level pump trip to prevent the respective transfer pumps from running dry.

A high level switch is provided on the Raw Water Tank to give an alarm and shut down the Raw Water Supply Pump in case the tank level control system fails.

The Potable Water Hydropneumatic Tank is provided with a safety relief valve.

Filtered Water Pumps and Raw Water Transfer Pumps are provided with minimum recirculation flow orifices to prevent the pumps from overheating during periods of low flow demand.

Demineralizers are provided with effluent strainers to prevent resin from entering the condensate system in case the demineralizer internals fail.

Tanks, piping and valves are designed for pressures which exceed the pump shutoff heads. The Filtered Water Storage Tank and Raw Water Storage Tank are supplied with overflows.

Safety showers and eye washes are provided in the areas where sulfuric acid and sodium hydroxide for water treatment are stored and handled.

3.2 HAZARDS

A personnel hazard exists in the areas where acid and caustic are stored and handled. The equipment in these areas is designed to minimize leakage and exposure of personnel to the chemicals. These chemicals can cause severe burning when they come in contact with the body.

3.3 PRECAUTIONS

Personnel protective equipment is required when handling acid or caustic and when doing maintenance or service in the chemical area. Workers should be completely protected with chemical goggles and face shields; and with neoprene coats, pants, and long rolled-cuff gloves. Any spillage on the skin should be washed immediately with copious quantities of water. Operators should check safety showers and eyewashes daily.

4.0 MODES OF OPERATION

4.1 STARTUP

Initial startup takes place after the tanks have been cleaned; pumps aligned, packed, and lubricated; piping and equipment hydrotested; pipe lines flushed clean; electrical wiring checked; and instruments and controls adjusted and calibrated.

The valves in the well water supply line are opened to fill the Filtered Water Tank and the Backup Fire Service Water Storage Tank. Close the well water supply valves at the tanks when they are full. Capacity available in the Filtered Water Tank is 100,000 gal. The remaining 300,000 gal. are available for fire service only.

Valves are opened to allow raw water to enter the Raw Water Storage Tank, and one Raw Water Supply Pump is started to fill the Raw Water Storage Tank to the high level. The level control valve is adjusted to maintain a high level range in the tank.

The Plant Makeup Demineralizer System should have been checked, acid and caustic storage tanks filled, and equipment ready for regeneration of each ion exchange unit. The regeneration waste tank and equipment should be ready to accept waste solutions, neutralize to an acceptable pH, and be ready to allow pumping out the waste solution.

The Condensate Storage Tank should be available to receive demineralized water if the main condensate-feedwater system is not yet in service.

The valves at one Filtered Water Pump are opened to allow water to be pumped to the makeup demineralizer system. Make sure the minimum recirculation flow system is in service. The required number of regenerations are performed on each demineralizer unit as recommended by the demineralizer supplier. After regenerations are complete, one train is valved off and the other train operated so as to produce demineralized water at design flow to the Condensate Storage Tank. The demineralizer train is recycled or shut down when the tank is full.

The Raw Water Treatment System should have been checked; chemicals should have been ordered; and the system should be ready for operation to produce filtered water.

One Raw Water Transfer Pump is started (check that the minimum recirculation flow is in service) to allow water to be processed through the Raw Water Treatment System at design flow. Chemical dosages are adjusted as recommended by the equipment supplier. Filtered water will replenish the water previously withdrawn from the Filtered Water Tank used to make demineralized water.

The Potable Water System should be installed, tested, disinfected, and ready to receive water from the city water supply piping. Air should be available at the Hydropneumatic Tank. The valves at one Potable Water Booster Pump are opened at the Hydropneumatic Tank. The air pressure controller at the tank is adjusted so that air is admitted below a predetermined setting. One pump is started. The tank high level and low pressure switches are adjusted so that the Booster Pump cuts off at the high level setting and starts at the low pressure setting. Pressure control will depend on the physical characteristics of the potable water distribution system. The low pressure setting should be such that water is delivered adequately to the most remote part of the system.

4.2 NORMAL OPERATION

The Plant Makeup Water System should operate normally on a continuous flow basis. This will depend on the nearly constant demand for cooling tower makeup, continuous filtered water uses, and demineralized makeup to the main power cycle.

It is intended that filtered water be used primarily for potable water uses and for emergency filtered water supply. The Filtered Water Pump draws water from the Filtered Water Tank and pumps it continuously through one demineralizer train for treatment and for continuous miscellaneous filtered water uses (such as pump gland flushing and mechanical seals). The demineralized water is used to make up losses from the power cycle, such as boiler drum blowdown, condenser and deaerater vents, continuous sampling, and equipment leakage.

Water drawn from the Filtered Water Tank may be replenished from a well water supply, or the Raw Water Treatment System. Raw water is also used continuously for cooling tower makeup. Cooling tower system losses are caused by evaporation, blowdown and drift. Raw water is continuously withdrawn from the Raw Water Storage Tank and continuously replenished by the Raw Water Supply Pump (well water or other available supply). Raw Water Tank level is maintained by the level control valve.

The equipment suppliers' operating instructions shall be followed for operation of the Raw Water Treatment and Makeup Demineralizer Systems.

4.3 SHUTDOWN

The systems are shut down primarily by switching off operating pumps, and closing major equipment isolating valves when necessary for maintenance.

The well water supply valving and the plant air supply shall be maintained as is, so that potable water is available for use throughout the plant.

The valves on water lines supplying the Fire Service Pumps must remain open.

Refer to the equipment suppliers' operating instructions for use in shutting down the Raw Water Treatment and Makeup Demineralizer Systems.

4.4 SPECIAL OR INFREQUENT OPERATION

Special operation occurs during a plant unit shutdown. These scheduled outages require large quantities of water for various cleaning and washing operations.

Filtered water may be needed for boiler circuit chemical cleaning and for cleaning and flushing of miscellaneous equipment and piping.

Large quantities of raw water are required for washing fly ash and soot from the air heaters, low temperature economizer, precipitator, and from inside the chimney. During this period of high water usage, it may be necessary to maintain the Raw Water Storage Tank level by operating both Raw Water Supply Pumps simultaneously.

If the use of filtered water exceeds the capacity of the Raw Water Treatment System, replenishment can be supplemented by water from the Filtered Water Tank. This condition might also occur during a fire at the plant.

High or low level alarms at any of the water tanks may be actuated. The high level switch on the Raw Water Tank may also be actuated. If any of these occur, the reason for the condition should be determined and corrected.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

The Plant Makeup Water System requires daily operator surveillance. Tank levels are monitored on the in-house computer. Operators should make periodic rounds to make sure pressure gages are reading their normal ranges, treatment plants are producing acceptable water quality, pumps are lubricated and gland leakage adjusted properly, and air pressure is indicated at any controls where required. Unusual noises and vibrations should also be detected during the rounds.

5.2 INSERVICE INSPECTION

All pumps, tanks, piping, valves, controls, gages, pipe supports, etc., shall be inspected periodically during system operation to ascertain that the system is operating properly. Any locations where excessive water or air leakage is detected should be noted and reported.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., depending on the recommendations of the equipment manufacturer. In general, the part

will be replaced during planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturers' Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT

SYSTEM DESIGN DESCRIPTION

PLANT MAKEUP WATER SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

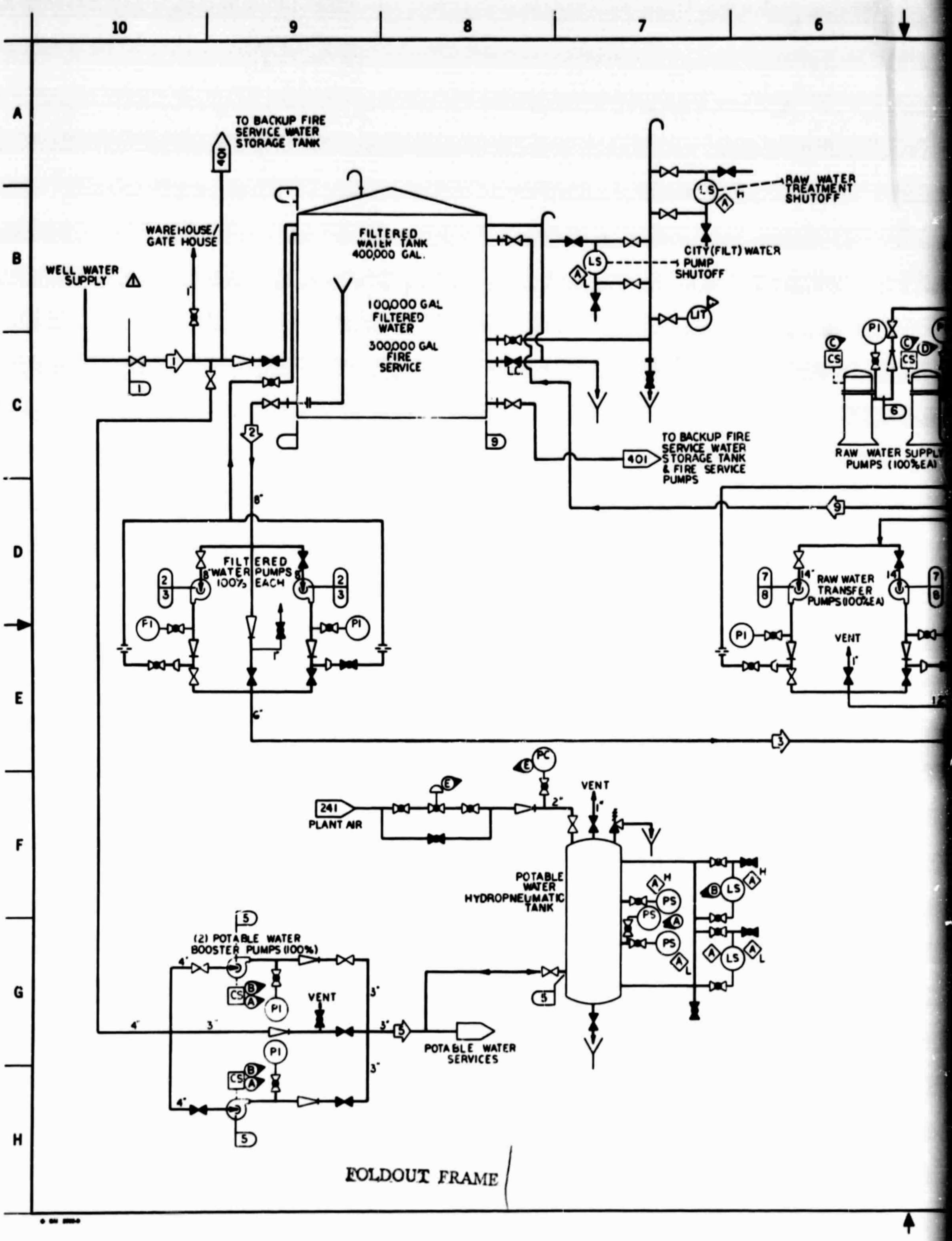
REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Plant Makeup Water	8270-1-582-302-161

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions
Condensate
Fire Service Water
Circulating Water

Plant Heat and Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001
Water Balance	8270-1-550-318-001



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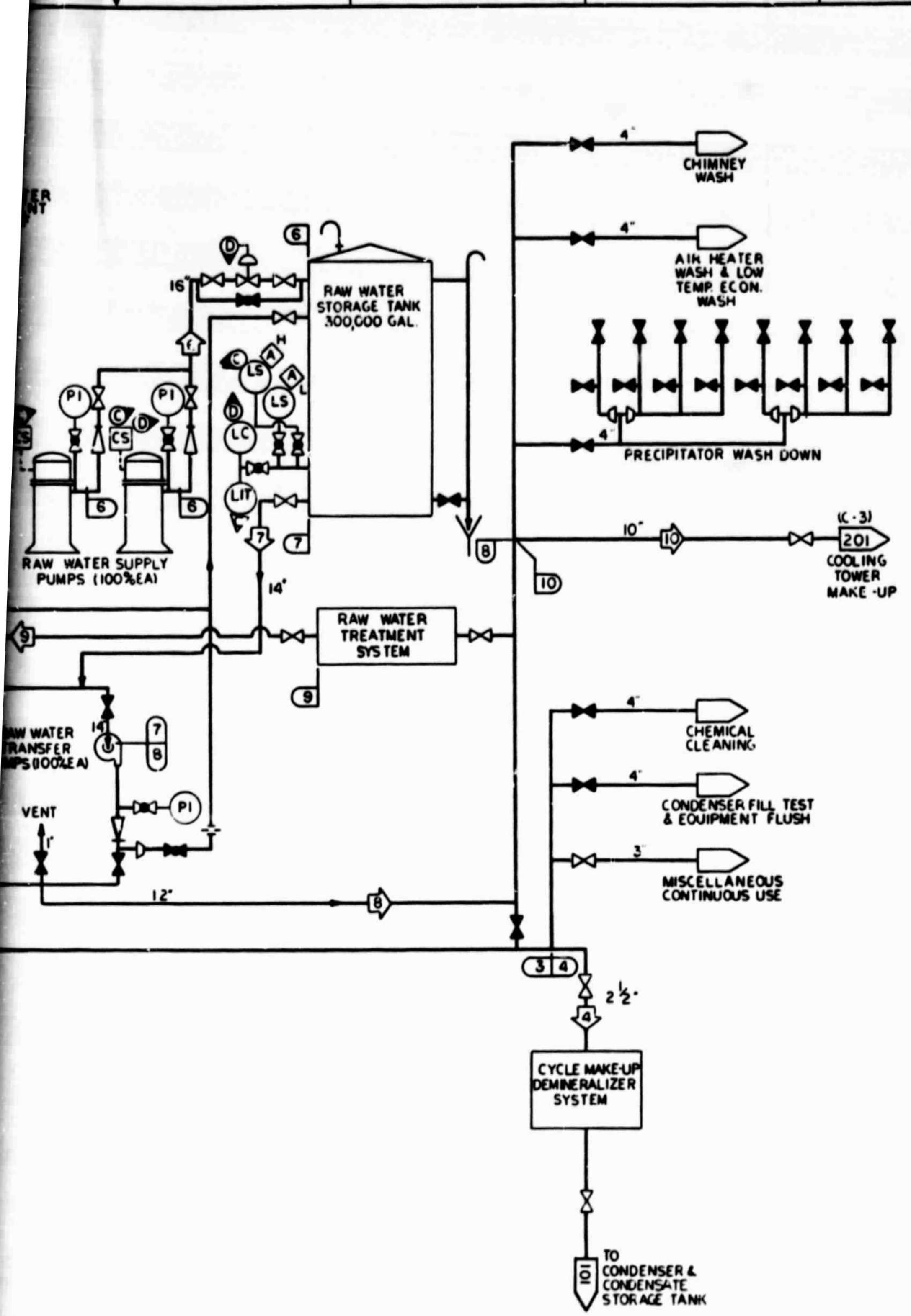

OPERATING DATA

#	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV.
1	150	25	70		INTERMITTENT	
2	185	25	70			
3	185	100	70			
4	35	100	70		1.5% x MIN.STM.	
5	150	65	70		INTERMITTENT	
6	3585	100	70			
7	3585	20	70			
8	3585	130	70			
9	185	30	70			
10	3400	130	70		VARIABLE	

DESIGN DATA

#	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	500	100	100			
2	600	50	100			
3	520	150	100			
4	70	150	100		3% x MIN.STM.FL.	
5	150	100	100			
6	4100	150	100			
7	4100	50	100			
8	4100	150	100			
9	520	50	100			
10	3400	150	100		3.5% x CIRC.H2O.FL.	

FOLDOUT FRAME 2

I.D. NO. C-371-897

DATE	RELEASED FOR	ENGR.
3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

PLANT MAKE-UP WATER SDD-161

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

8270-1-582-302-161 REV 1
DRAWING NUMBER

REVISIONS
1 NL 8-10-81 WELL WATER SUPPLY WAS CITY WATER; ADDED H.RIGO, DATE & SDD NO. IN TITLE BLOCK

SYSTEM DESIGN DESCRIPTION

SDD-181

SAMPLING SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-633-302-181

J A Bolognese 3/4/81

SYSTEM ENGINEER DATE

A L Mann / TC Reitz 3/5/81

REVIEWED DATE

3/10/81

APPROVED DATE

Revision: 1

Date: September 25, 1981

Approved:

MHE-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
SAMPLING SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Sampling System as depicted on Fluid System Diagram 8270-1-633-302-181, Sampling. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Sampling System is designed to collect and cool miscellaneous water and steam samples, automatically regulate the sample temperatures and pressures, continuously monitor and record chemical characteristics and concentrations, and provide for manual grab samples for laboratory analysis. Chemical constituents are to be maintained within certain specified limits established by the MHD components, HR/SR, turbine and other equipment suppliers.

1.2 SYSTEM INTERFACES

Major equipment components of the Sampling System include a Primary Cooling Rack, Sampling Rack, Recorder-Analyzer Panel, Refrigeration Unit, Condenser Sampling Pumps, sample tubing, piping and valves. The Sampling System interfaces with the following systems:

Condensate
Boiler Feedwater
Feedwater Heater Drips
Main Steam and Reheat Steam
Closed Cycle Cooling Water
Feedwater Heater and Misc. Drains and Vents
Circulating and Service Water

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings and system limits in the selection of required components. Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations and guides by governmental agencies, recognized standards organizations, and Gilbert Associates Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides by the following organizations:

1. American National Standards Institute (ANSI).
2. American Society of Mechanical Engineers (ASME).
3. American Society for Testing and Materials (ASTM).
4. American Welding Society (AWS).
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS).

6. Pipe Fabrication Institute (PFI).
7. Occupational Safety and Health Administration (OSHA).
8. Instrument Society of America (ISA).

1.3.2 Design Parameters

1.3.2.1 Sample operating pressures and temperatures at full unit load are as follows:

	Source	Temperature °F	Pressure psig
AE-1	Condenser Hotwell	101	1-5" Hg Abs.-100
AE-2	Condensate Pump Discharge	101	100
AE-3	Condensate Demin. Outlet	101	50
AE4A,4B	H.P. Heater Drains	369	155
AE-5	BFW Booster Pump Discharge	215	235
AE-6	BFW Pump Suction	303	200
AE-7	H.T. Economizer Inlet	450	2270
AE-8	Combustor FW Inlet	530	2270
AE-9	Radiant Boiler Inlet	637	2270
AE-10	Drum Steam	637	2000
AE-11	Boiler Blowdown	637	2000
AE-12	Main Steam	1005	1900
AE-13	Cold Reheat Steam	650	435
AE-14	Hot Reheat Steam	1000	415

1.3.2.2 Design pressures and temperatures of the sampling equipment up to the first shutoff valve on the Primary Cooler Rack are the same as those for the system from which the sample is taken.

1.3.2.3 Sample flows are in the range of 200 to 1000 cc/min. depending on the type of analysis required and the manufacturer's recommended flow for each specific flow cell or analyzer.

1.3.2.4 The Secondary Cooler system is designed to maintain a constant sample temperature of 77°F ± 1°F to avoid the use of temperature compensators and assure accuracy of measurement. A chilled water unit is required to accomplish this.

1.3.2.5 Sample flow velocity is to be maintained at 2 ft/min. minimum to prevent settling of suspended iron in sample tubing.

1.3.2.6 Design temperature for Closed Cycle Cooling Water is 85°F.

2.0 DESIGN DESCRIPTION

The Sampling System consists of the following major components:

1. Sampling Rack
2. Recorder-Analyzer Panel

3. Primary Cooler Rack
4. Chiller Unit
5. Condenser Sampling Pumps.

These are described in Section 2.2.

2.1 SUMMARY DESCRIPTION

Condensate, feedwater, heater drains, steam and blowdown samples are conveyed in stainless steel tubing to a Primary Cooler Rack. They are cooled to the 110°F to 120°F range using Closed Cycle Cooling Water. Samples above 200 psig are reduced in pressure through pressure reducing devices.

The samples are then conveyed to a Sampling Rack where they are further cooled to a constant temperature of 77°F. A sample chiller unit is provided to accomplish this secondary cooling. The samples are maintained at a constant pressure and directed to pH and conductivity flow cells mounted on the Sampling Rack. Provision is also made to obtain grab samples for laboratory analysis.

Samples which require continuous automatic analysis and recording are conveyed after cooling to the Recorder-Analyzer Panel. Analyzers are provided to measure sodium, dissolved oxygen, silica, and hydrazine from the appropriate samples as shown on the fluid system diagram. Samples are collected and drained to the plant drain system.

Condenser samples under vacuum are collected and pumped to the Sampling Rack. These are continuously monitored for cation conductivity and sodium to detect any condenser tube leakage.

Pressure and temperature indicators are provided to make sure that pressure and temperature reductions are accomplished as required. Flow indicators are used to set flow rates to cells and analyzers as recommended by equipment suppliers. Relief valves are provided in both the high and low pressure section of the sampling lines in the event of inadvertent closing of certain valves.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 Primary Cooler Rack

One Primary Cooler Rack is furnished which is free-standing and floor-mounted. The rack has mounted on it the sample inlet isolation valves, primary coolers, pressure reducing devices, temperature and pressure indicators. Blowdown valves are furnished to flush the sample to waste before using for analysis. The rack is completely assembled.

2.2.1.2 Sampling Rack

The Sampling Rack contains the constant temperature secondary coolers, pH and conductivity cells and indicators, temperature and pressure indicators, grab sample tubing, pressure regulating valves, and relief valves. It is completely assembled, wired and piped on a self supporting welded steel frame. All sample tubing is stainless steel.

2.2.1.3 Recorder-Analyzer Panel

The Recorder-Analyzer Panel is enclosed and of all welded construction. Recorders and analyzers are flush mounted on the panel with flow indicators for sample flow rate. The panel is completely shop assembled, wired and piped with hinged access doors in the rear. All wiring terminates at conveniently located terminal blocks.

The following recorders and analyzers are furnished. They will be described more fully after purchase.

1. Conductivity Recorder-Controller for BFW Booster Pump Discharge sample to control pump stroke automatically for ammonia feed. (Conductivity is used for pH control).

2. Hydrazine Recorder - Controller for H.T. Economizer Inlet sample to control pump stroke automatically for hydrazine feed.

3. Multipoint recorders for:

   a. pH
   b. Conductivity
   c. Silica
   d. Dissolved Oxygen

4. Automatic Continuous Analyzers for

   a. Sodium (2)
   b. Silica (3)
   c. Dissolved Oxygen (3)
   d. Hydrazine (1)

The recorders will be ..rnished with alarm contacts as required and will be connected to an annunciator on the panel indicating which sample is alarmed. A Common alarm will be transmitted to the main control room indicating "Sampling System-Trouble".

Switches with red and green lamps will also be provided to operate the Condenser Sampling Pumps and chiller unit.

2.2.1.4 Sample Chiller Unit

The Sample Chiller unit is water cooled and provides chilled water to the secondary coolers so as to maintain a constant sample temperature at

77°F ± 1°F for analysis. The chiller unit includes a refrigeration compressor and circulating water pump for the chilled water. Temperature controls are included to maintain a constant sample outlet temperature from the secondary coolers.

2.2.1.5 Condenser Sampling Pumps

Two 100 percent Condenser Sampling Pumps are provided. These are diaphragm type positive displacement pumps suitable for full vacuum service. The capacity of each pump is sufficient to provide sample flow for analysis of conductivity, sodium and a grab sample. The pump construction is of stainless steel. Pulsation dampeners are provided to minimize excessive pressure fluctuations.

2.2.2 Piping and Valves

Sample tubing is 304 stainless steel ASTM A213 with socket weld couplings and fittings above 300 psig and compression type fittings under 300 psig. Valves in the high pressure samples up to the Sampling Rack are rated the same as the system from which the sample is taken. Valves in the low pressure part of the sampling tubing are stainless steel with tubing ends.

2.2.3 Electrical

Pump motors are 460 volt, 3 phase, 60 Hz with power supplied from the 480 volt motor control centers. Controls, analyzers, recorders and solenoid valves will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls, and Alarms

These are covered under the Recorder-Analyzer Panel. Description in Section 2.2.1.

3.0 SYSTEM PROTECTION AND SAFETY DEVICES

3.1 PROTECTIVE DEVICES

Relief valves are provided for high pressure and low pressure relief in case of accidental valve operation for each of the samples.

The Condenser Sampling Pumps are provided with internal relief in case of accidental valve operation on the discharge piping.

Blowdown valves are provided on the Primary Cooler Rack to flush initial dirty samples to waste before allowing the sample to enter sensitive measuring cells and analysis elements.

3.2 HAZARDS

Major hazards consist of dangers involved with high temperature samples at the sampling equipment and the possibility of a high temperature - high pressure fluid leak. If any leakage of high pressure - high temperature fluid occurs,

the sample should be turned off and the leaking joint reported for maintenance and repair. Insulation is to be provided where personnel might accidentally come in contact with high temperature sample equipment.

3.3 PRECAUTIONS

Make sure cooling water is flowing through the Primary Coolers.
High pressure samples have pressure reducing devices to take pressure drop instead of using a valve, thus minimizing damage to the valve disc and seat. Valves downstream of the pressure reducing device should not be closed unless the sample inlet valve is closed first. A safety valve is provided to relieve pressure in the event this condition inadvertently occurs.

The closed cooling cycle associated with the package chiller unit should be completely filled before starting the chiller.

Refer to the chiller manufacturer's instructions for precautions prior to starting. Items to be checked are refrigerant valves, condenser cooling water flow, chilled water pump operation, and power supply.

4.0 MODES OF OPERATION

4.1 STARTUP

4.1.1 All sampling root valves are to be open where the sample originates.

4.1.2 Cooling water to the primary coolers is to be turned on by opening appropriate valves.

4.1.3 Makeup water supply to the chilled water closed cooling system is to be turned on by opening appropriate valves.

4.1.4 Start sample chiller unit in accordance with the manufacturer's instructions. Set initial chilled water temperature to 50°F-60°F. This can be reset as required to give 77°F sample temperatures out of the secondary coolers.

4.1.5 Blowdown the samples to waste at the Primary Cooler Rack. Close blowdown valve when the appearance of the sample stabilizes.

4.1.6 Open the valves which allow samples to flow through the secondary coolers and for grab samples. All other valves to measuring cells and analyzers are to be closed.

4.1.7 Sample bottles for laboratory analysis should be available, properly cleaned and labeled.

4.1.8 Instrument air is to be available for the Recorder-Analyzer Panel and any other pneumatic controllers.

4.2 NORMAL OPERATION

4.2.1 Open the sample inlet valves at the top of the sampling rack. Allow each sample line to purge itself through the open grab sample valve, into the sampling sink and to waste. This should be done for a minimum of one-half hour.

4.2.2 When purging of the sampling line is complete, start to open valves which allow the samples to flow through the conductivity and pH cells, dissolved oxygen, hydrazine, sodium and silica analyzers. Adjust flow rates to these instruments in accordance with manufacturer's instructions.

4.2.3 The inlet sample valves for samples having pressure reducing elements should be opened wide to allow the pressure drop to be taken across the pressure reducing device.

4.2.4 It is desirable to have grab samples running continuously in order to increase sample velocities, thereby decreasing lag time. Grab samples to the sink should be reclaimed whenever possible.

4.2.5 All samples which are being continuously recorded are to be checked periodically by laboratory analysis to determine whether indicated and recorded valves are reliable.

4.2.6 Cation conductivity will be recorded normally except for boiler blowdown and BFW booster pump discharge. These two samples will be recorded for normal conductivity. The cation exchangers upstream of conductivity cells will remove ammonia and thus eliminate the increased conductivity effect of this chemical additive. If conductivity increases above normal readings, it must be determined whether the cycle is being contaminated or whether the cation exchanger resin needs regeneration. Regeneration, when required, should be done in accordance with manufacturer's instructions.

4.2.7 Open all condenser sampling valves, Sampling Pump suction valves and the sample return valves for priming one pump. Start the Sampling Pump. When flow is established, open the valves at the sampling rack to allow flow for a grab sample. Close the sample return valve to the condenser. When the sample clears, allow it to enter the conductivity cell and sodium analyzer.

4.3 SHUTDOWN

The sampling system can be shutdown for maintenance of individual cells, cation exchangers, instruments, or valves by closing the first inlet valve at the sampling rack. It is recommended that the root valves also be closed when performing maintenance.

The complete system can be shutdown in accordance with the following procedures:

Close all sample rack inlet valves and root valves.

Stop the condenser sample pumps.

Close cooling water inlet and outlet valves at the primary cooling coil rack as well as sample inlet valves at this rack.

Switch off the sample chiller unit.

Switch off all analyzers and recorders.

4.4 SPECIAL OR INFREQUENT OPERATION

4.4.1 An alarm indicating condenser hotwell high cation conductivity or sodium may occur. If a significant increase is noted, all valves, except one, are closed at the condenser, and that sample is analyzed. Each valve is individually opened and closed in a like manner until there is a continuous indication of contamination from cooling water. This procedure helps in locating the approximate area where a condenser tube or tube sheet is leaking.

4.4.2 There may be times when it is desirable to record Condensate Demin. Outlet sodium and Main Steam silica. These are piped as alternate samples at the Recorder-Analyzer Panel. Close the valve for the normal samples to the analyzers and open the valves allowing the afore-mentioned samples to enter the respective sodium and silica analyzers.

5.0 <u>MAINTENANCE</u>

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

The Sampling System requires operator attention each day. Operators should periodically check the sampling equipment to make sure of the following:

1. Samples are being cooled to the required temperatures.
2. Samples are being reduced in pressure to the required ranges.
3. Sample flows are set properly and being maintained.
4. Analyzers and recorders are functioning properly.
5. Sample chiller unit is operating to maintain secondary cooler samples at 77°F.
6. Condenser sampling pump is pumping adequate sample flow to the Sampling Rack.
7. There should be no significant leakages of sample at the sampling equipment area.

5.2 INSERVICE INSPECTION

Pumps, valves, piping, sample chiller unit, instruments, recorders and analyzers shall be inspected periodically during system operation to ascertain that the system is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Maintenance instructions can be found in the individual manufacturer's instructions and should be followed on a scheduled basis.

Some items which will require regular maintenance are:

1. Cleaning and calibration of pH and conductivity cells.
2. Replacing of cation resin charges and regenerating the exhausted resin.
3. Cleaning critical items in the automatic analyzers, recalibrating, and refilling reagents where used.
4. Cleaning out pressure reducing devices.
5. Refilling recorder ink supplies as required.
6. Maintaining the chiller as per manufacturer's instructions.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
SAMPLING SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

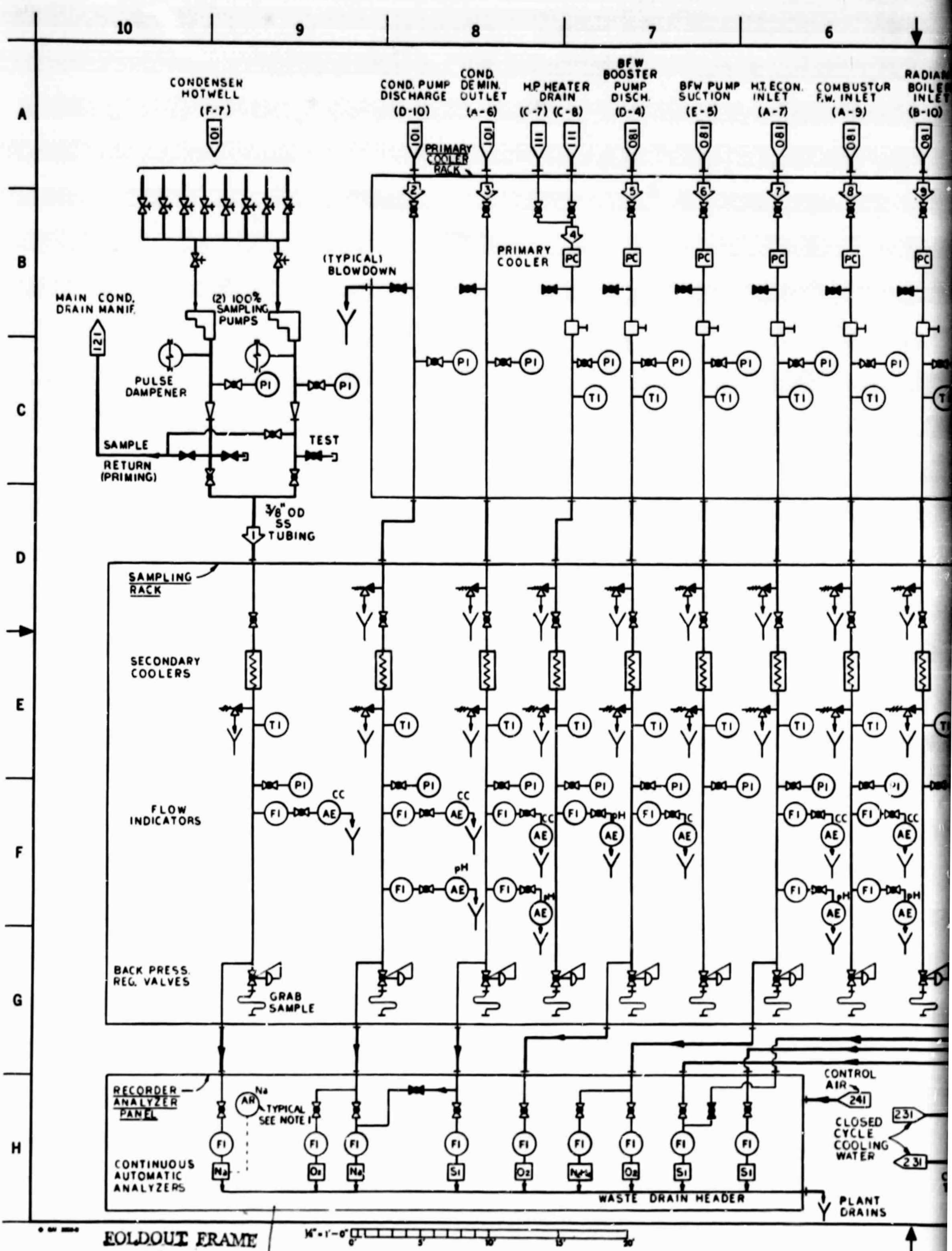
REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams	Diagram No.
Sampling	8270-1-633-302-181

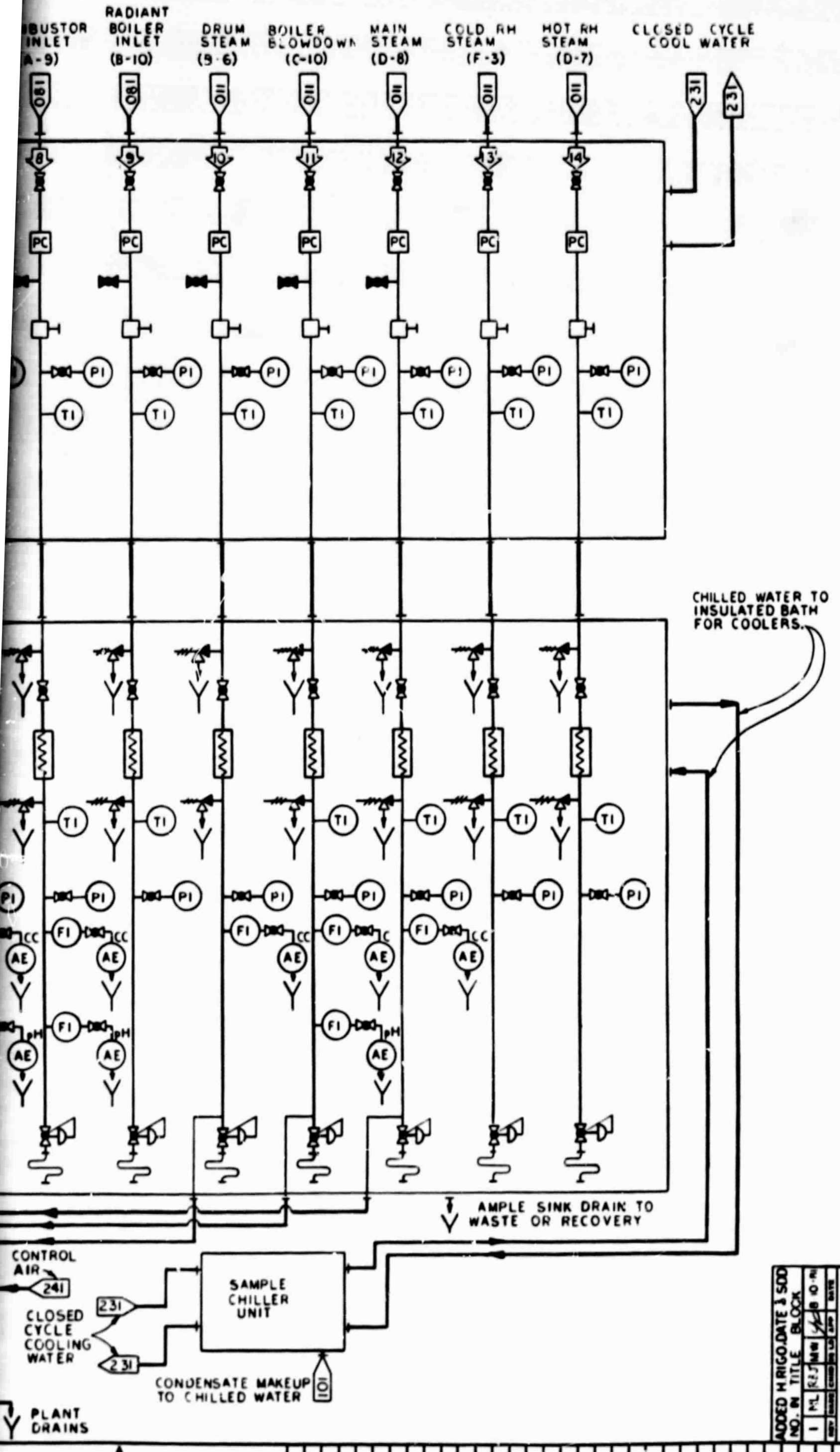
REFERENCE DOCUMENTS - NOT ATTACHED

Fluid System Diagrams	
Main & Reheat Steam	8270-1-501-302-111
Boiler Feedwater	8270-1-521-302-081
Condensate	8270-1-511-302-101
Feedwater Heater Drips	8270-1-525-302-111
Closed Cycle Cooling Water	8270-1-531-302-231

Plant Heat & Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001



CONDENSER HOTWELL (F-7)
COND. PUMP DISCHARGE (D-10)
COND. DEMIN. OUTLET (A-6)
H.P HEATER DRAIN (C-7) (C-8)
BFW BOOSTER PUMP DISCH. (D-4)
BFW PUMP SUCTION (E-5)
H.T. ECON. INLET (A-7)
COMBUSTOR F.W. INLET (A-9)
RADIANT BOILER INLET (B-10)
PRIMARY COOLER RACK
PRIMARY COOLER
(TYPICAL) BLOWDOWN
MAIN COND. DRAIN MANIF.
(2) 100% SAMPLING PUMPS
PULSE DAMPENER
SAMPLE RETURN (PRIMING)
TEST
3/8" OD SS TUBING
SAMPLING RACK
SECONDARY COOLERS
FLOW INDICATORS
BACK PRESS. REG. VALVES
GRAB SAMPLE
RECORDER ANALYZER PANEL
TYPICAL SEE NOTE 1
CONTINUOUS AUTOMATIC ANALYZERS
CONTROL AIR
CLOSED CYCLE COOLING WATER
WASTE DRAIN HEADER
PLANT DRAINS
FOLDOUT FRAME



OPERATING DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1		1.5Hg Abs	101		100 PSIG MAX, TBD	
2		100	101		TBD	
3		50	101		TBD	
4		155	369			
5		235	215			
6		200	303			
7		2270	450			
8		2270	530			
9		2270	637			
10		2000	637			
11		2000	637			
12		1900	600			
13		435	650			
14		415	1000		TBD	

DESIGN DATA

#	FLOW lb/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV

NOTE:

1. RECORDERS MAY BE MULTIPOINT AND RECORD MORE THAN ONE ANALYSIS OF THE SAME TYPE.

FOLDOUT FRAME 2

I.D. NO. C-373-030

3 27 81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	
QTY.	RELEASED FOR	ENGR.

1	ADDED H. RIGO, DATE & SDD NO. IN TITLE BLOCK

REVISIONS

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

SAMPLING SDD-181

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

SCALE NONE

8270-1-633-302-181 REV 1

DRAWING NUMBER

SYSTEM DESIGN DESCRIPTION

SDD-201

CIRCULATING WATER SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-571-302-201

R. B. Jensen Feb. 5, 1981

SYSTEM ENGINEER DATE

T. C. Retz Feb 27, 1981

2/26/81

REVIEWED DATE

Feb. 26, 1981

APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved:

MDH-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CIRCULATING WATER SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Circulating Water System as depicted on Fluid System Diagram 8270-1-571-302-201, Circulating and Service Water. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, components, operating modes, safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Circulating Water System is designed to supply cooling water for the main steam condenser, three turbine drive condensers, and power plant heat exchangers.

1.2 SYSTEM INTERFACES

Major equipment involved with the Circulating Water System include the Cooling Tower complex, the Circulating Water pumps, the Service Water pumps, the Air Separation Unit (ASU) aftercooler Cooling Water pumps, the plant heat exchangers, piping, valves, and controls. The plant heat exchangers (closed cycle coolers and the four steam surface condensers) interface directly with the Circulating Water System. Other indirect interfaces with the system are as follows:

- Steam turbine exhausts
- Closed Cycle cooling water
- Cooling Tower makeup
- Cooling Tower blowdown
- Cooling Tower chemical treatment
- Sampling
- ASU air compressor cooling

Cooling tower blowdown is taken from the discharge side of the circulating water pumps. The rate is determined by the water chemistry and discharge regulations. Blowdown is normally discharged to a holding pond or used in the Slag Management System.

Cooling tower makeup is supplied from the raw water supply header which is a part of the Plant Makeup Water System.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure/temperature ratings, and system limits to be used in the selection of the required components. Engineering design criteria are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)

2. American Society of Mechanical Engineers (ASME)

3. American Society for Testing and Materials (ASTM)

4. American Welding Society (AWS)

5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)

6. Pipe Fabricators Institute (PFI)

7. Occupational Safety and Health Administration (OSHA)

8. Instrument Society of America (ISA)

9. National Fire Protection Association (NFPA)

10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures, and pipe sizing flow rates are taken from the system heat balance diagram and tabulated on the Fluid System Diagram 8270-1-571-302-201. Flow rates are those occurring with main steam turbine valves wide open and with the Heat Recovery/Seed Recovery (HR/SR) steam outlet at maximum continuous rating conditions. Water pipe sizing is based on pressure drop which is an engineering judgement with reasonable water velocities. Water velocity is limited to 10 feet per second.

The design pressure within all pumping systems is based upon pump shutoff head and pressure transients. For the Circulating and Service Water pumps the operating pressure is the head required to lift the water to the height needed by the cooling tower complex plus pipe friction throughout the system at maximum flow. For the ASU cooling pumps the operating pressure is the head required to inject water into the aftercooler (which is a closed pressure vessel at 60 psig) and to lift the water exiting to the height required by the cooling tower plus pipe and valve friction.

2.0 DESIGN DESCRIPTION

The Circulating Water System consists of a mechanical draft cooling tower complex with concrete basins and flume, pump intake water screens, three circulating water pumps, three service water pumps, heat exchangers, two ASU aftercooler pumps, piping, valves, and controls.

2.1 SUMMARY DESCRIPTION

The circulating water flow path is from the cooling tower complex, (two 4-cell mechanical draft, crossflow units) into a flume, through fixed intake water screens to the suctions of vertical circulating water pumps. The circulating water pumps deliver cold water to steam surface condensers, where the water picks up heat from the condensers and then delivers it to an elevated position on the cooling towers. The hot water is sprayed over cooling tower trays

where it flows by gravity to the basins. Heat from the water is exchanged by partial evaporation and contact with the air drawn into the cooling towers by fans. The basins collect the cooled water and the flume delivers it to the pumps.

The service water pumps take their suction from the same source as the circulating water pumps. Cold service water is delivered to the plant closed cycle cooling system heat exchangers. The closed cycle heat exchangers interface with a demineralized water system for critical equipment cooling. Hot service water is returned to the cooling towers.

The ASU air compressor aftercooler cooling water pumps take their suction from the Service Water System discharge header through duplex filters. One full capacity pump is normally operated to discharge cold water, at 80 psig, to the aftercooler. The aftercooler is an air/water spray contact type unit wherein the water picks up heat from the compressed air stream by direct contact. The heated water falls to a sump at the bottom of the aftercooler and is discharged through a control valve directly to the cooling tower complex.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major components of the Circulating Water System are the cooling tower complex, circulating and service water pumps, aftercooler pumps, and plant heat exchangers. The heat exchangers are described in interfacing system descriptions as covered in Section 1.2.

2.2.1.1 Cooling Towers

The cooling towers are mechanical draft, cross-flow types arranged as two parallel units of four cells each. Each cell is a single cooling tower entity, and consists of a structure to house side louvers, water trays, water distribution pipe header system, and a geared, slow speed fan mounted on top. The components are located above a part of the concrete basins. Air is drawn in horizontally on each side through louvers and moves up through the hot water spray and out the top by means of fans. The hot water (delivered by pipe risers from the condensers and heat exchangers) discharges to a header system on the top or fan deck of the cooling towers. The hot water is sprayed downward into trays. The water is cooled by latent and sensible heat transfer to the air. Cooling tower materials are non-combustible and suitable for the water chemistry involved. Cooling tower isolation valves are provided to bypass a percentage of the hot water during cold weather to prevent icing conditions. Each cell may be isolated for servicing if required at any time.

The performance of the total cooling tower complex is based on a heat input of 1,100 million Btu/hr, or cooling 96,000 gpm of circulating and service water from 92°F down to 69°F with an ambient wet-bulb temperature of 59°F.

Each of the two 4-cell cooling tower units will be approximately 125 feet long by 75 feet wide and 50 feet high. Each cooling tower fan will be driven by a 200 hp motor.

2.2.1.2 Circulating Water Pumps

The circulating water pumps are three 50 percent capacity units. They take their suction from the flume after the water screens and discharge cold water to the steam surface condensers through a suitable pipe header system.

Pump type	Vertical, mixed flow, submerged suction
No. of stages	2
Capacity	40,000 gpm
TDH	60 feet
Brake horsepower (@80% eff.)	758
Motor horsepower	800
Motor Power Supply	4160 V, 3ph, 60 Hz

Pump Materials:

Discharge column	Fabricated steel
Drive shaft	Alloy steel
Stuffing box	Cast iron
Discharge bowl	Cast iron
Impeller	Cast iron
Suction bell	Cast iron
Bearings	Rubber and bronze

2.2.1.3 Service Water Pumps

The three service water pumps are similar to the circulating water pumps, but are smaller in capacity and physical size. They discharge cold water to the closed cycle coolers, and ASU pumps.

Pump type	Vertical, mixed flow
No. of stages	2
Capacity	8000 gpm
TDH	60 feet
Brake horsepower (@80% eff.)	149
Motor horsepower	150
Motor power supply	460 v, 3 ph, 60 Hz

Pump Materials:

Discharge column	Fabricated steel
Discharge shaft	Alloy steel
Stuffing box	Cast iron
Discharge bowl	Cast iron
Impeller	Cast iron
Suction bell	Cast iron
Bearings	Rubber and bronze

2.2.1.4 ASU Aftercooler Pumps

The ASU aftercooler cooling water pumps are two 100 percent capacity units. They take suction from the service water discharge header and pump to higher pressure into the pressurized aftercooler, cooling the ASU air compresser throughput by means of spray evaporation and contact.

Pump type	**Horizontal centrifugal**
Capacity	**1000 gpm**
TDH	**140 feet**
Discharge pressure	**80 psig**
Suction pressure	**20 psig**
Brake horsepower (@ 80% eff.)	**45**
Motor horsepower	**50**
Motor Power supply	**460v, 3 ph, 60 Hz**

Pump Materials:

Casing	**Cast iron**
Shaft	**SAE-4340**
Shaft sleeves	**SAE-1103**
Stuffing box	**SAE-1000**
Impeller	**Cast iron**
Bearings	**Steel-roller bearings**

2.2.2 Piping and Valves

Motor operated butterfly valves and expansion joints are provided at the pump discharges and the inlet and outlet of each condenser. The valves at the pump discharges and makeup and blowdown valves are the only valves used for operation and control of the system. Condenser, cooling tower and heat exchanger valves are used for isolation. The circulating and service water pump valves are interlocked with the pump motors so that opening of the valves intiates pump startup at a predetermined valve opening point. All valves are designed in accordance with ANSI B16.34. The piping will be welded steel with welded joints in accordance with ANSI B31.1. Piping materials will be carbon steel in accordance with ASTM, A53 Grade B or A155 Class I Grade C55 or equal. Valve materials are compatible with pipe materials.

2.2.3 Electrical

Pump motors are controlled through electrical switch gear and motor control centers. The fan motors are controlled through motor control centers. Motor operated valves have motor control centers and/or power supplies.

2.2.4 Instruments, Controls, and Alarms

The Circulating Water System is provided with appropriate instrumentation for sensing water pressure and temperature at points commensurate with good design practice to monitor system performance. The circulating and

service water pump discharge valves are interlocked with the pump motor starting circuits. A bubbler system warns of excess pressure drop across the pump intake screens. The system will be monitored by the plant operators, plus the computer system to keep a running operational check of water temperature and pressure.

Pressure indication is provided on all pump discharges and at heat exchanger inlets and outlets. Differential pressure is sensed and alarmed across the duplex strainer and filter.

Temperature indication is provided on the inlets and outlets of all heat exchange equipment.

Pressure and temperature test points are provided throughout the system.

Cooling tower flume level is transmitted and alarmed to the main control room.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The motor and valve interlocks for the circulating and service water pumps protect the pumps from being driven in reverse. Each heat exchanger has tube side relief valves on the water boxes. The water boxes for the condensers have air relief valves for over pressure protection and to prevent air binding.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Circulating Water System beyond those normally observed in conjunction with low pressure and temperature piping. The motors on the pumps, fans and valve drives will require protective devices. The fans will require protective devices for the rotating blades.

3.3 PRECAUTIONS

Exposed pump drive shafts will have guards over the couplings between motor and pump. The large cooling tower fans will have chimneys surrounding each fan discharge. Relief valves will be shielded or diverted to a safe discharge point.

4.0 MODES OF OPERATION

4.1 STARTUP

The startup of the Circulating Water System requires no special procedures. The raw water makeup pumps are used to fill the basin and flume with water. One 50 percent circulating pump is started with the main condenser valves and cooling tower valves open. The second pump is started with the mechanical drive turbine condenser water valves open. The system

is trimmed according to the ambient conditions by taking out cooling tower cells or pumps. The service water pump flow is less and they can be started at any time. The ASU cooling pump is started after the service water pumps are in operation.

4.2 NORMAL OPERATION

Normal operation is to have two 50 percent circulating pumps operating with all the steam surface condensers operating, and with one cooling tower cell shutdown. Two 50 percent service water pumps will be operating in conjunction with one out of two 100 percent closed cycle heat exchangers and the plant heat exchangers operating. One ASU cooling pump in operation is considered normal.

4.3 SHUTDOWN

The Circulating and Service Water System is essential to the plant operation and cannot be shutdown unless the topping side plant is down. Individual components may be replaced on line by redundant components. Shutdown of a large vertical pump requires control interlocks with the discharge valve to prevent reverse rotation of the pump.

4.4 SPECIAL OR INFREQUENT OPERATION

The main steam surface condenser is designed to accept a steam dump (50 percent of main steam flow) from the Steam Bypass and Startup System. In the dump mode, it will be desirable to have all of the cooling tower cells in service to remove the excess heat.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record direct indicating instruments and may calculate performance per shift. The computer may be arranged to constantly monitor specified points to give a running check on performance. The indicating measurements would be used as a check on the computer readings.

5.2 INSERVICE INSPECTION

All the equipment listed previously shall be inspected while operating to assure they are physically in service: pump shafts are turning and pressures are indicated; fan blades are turning and air is moving; heat exchangers feel warm to the touch; and water level gages show condensate in the condenser hotwells. Indicating pressure and temperature instruments will monitor the performance of a piece of equipment and the fact that it is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operating personnel when equipment needs overhaul, repacking, or cleaning, in

accordance with the recommendations of the equipment manufacturer. In general, parts will be replaced during planned shutdowns when they are near the end of their recommended life cycles.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. Critical parts and parts requiring long lead (delivery) times will be kept in inventory at the plant.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CIRCULATING WATER SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

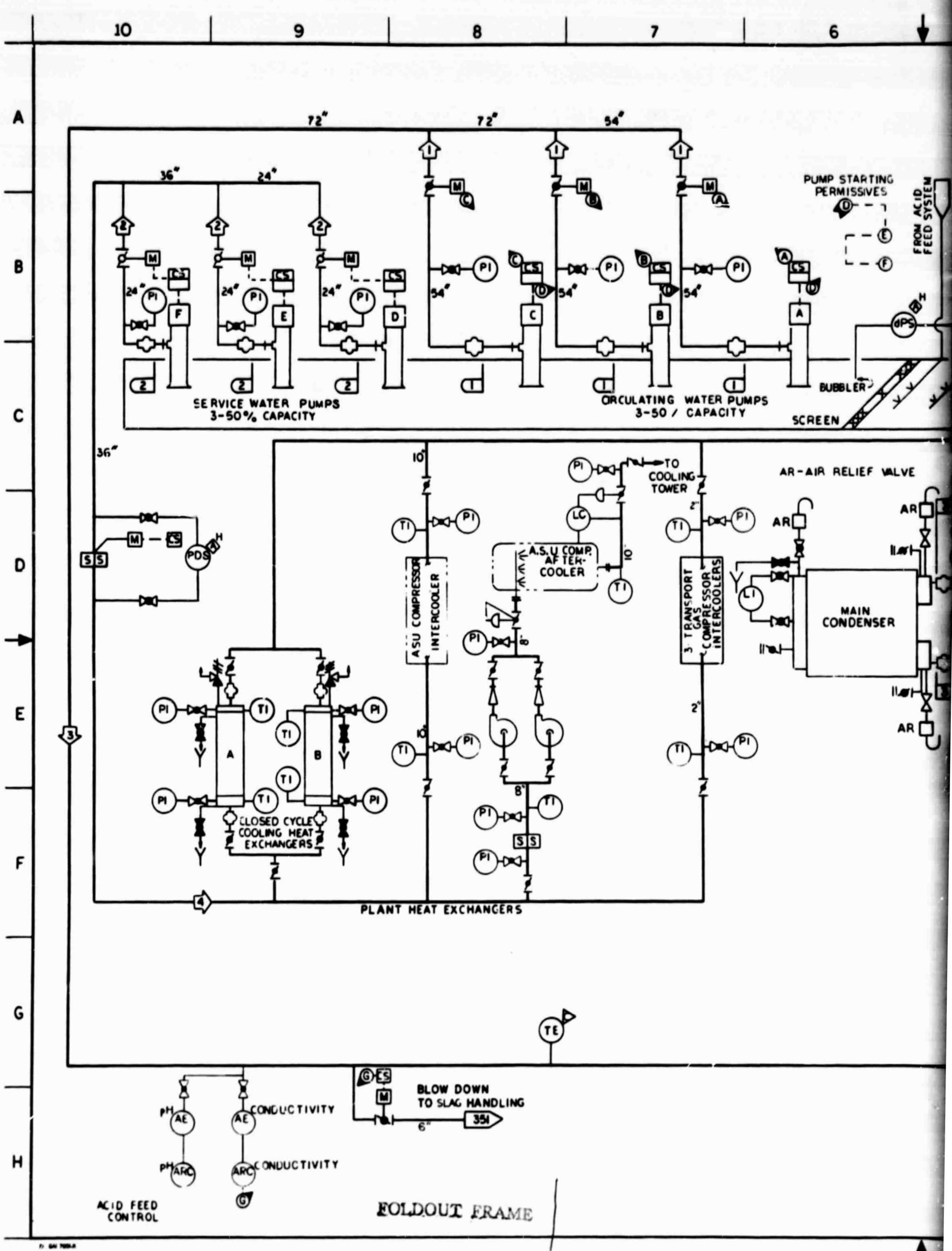
Fluid System Diagram	Diagram No.
Circulating and Service Water	8270-1-571-302-201

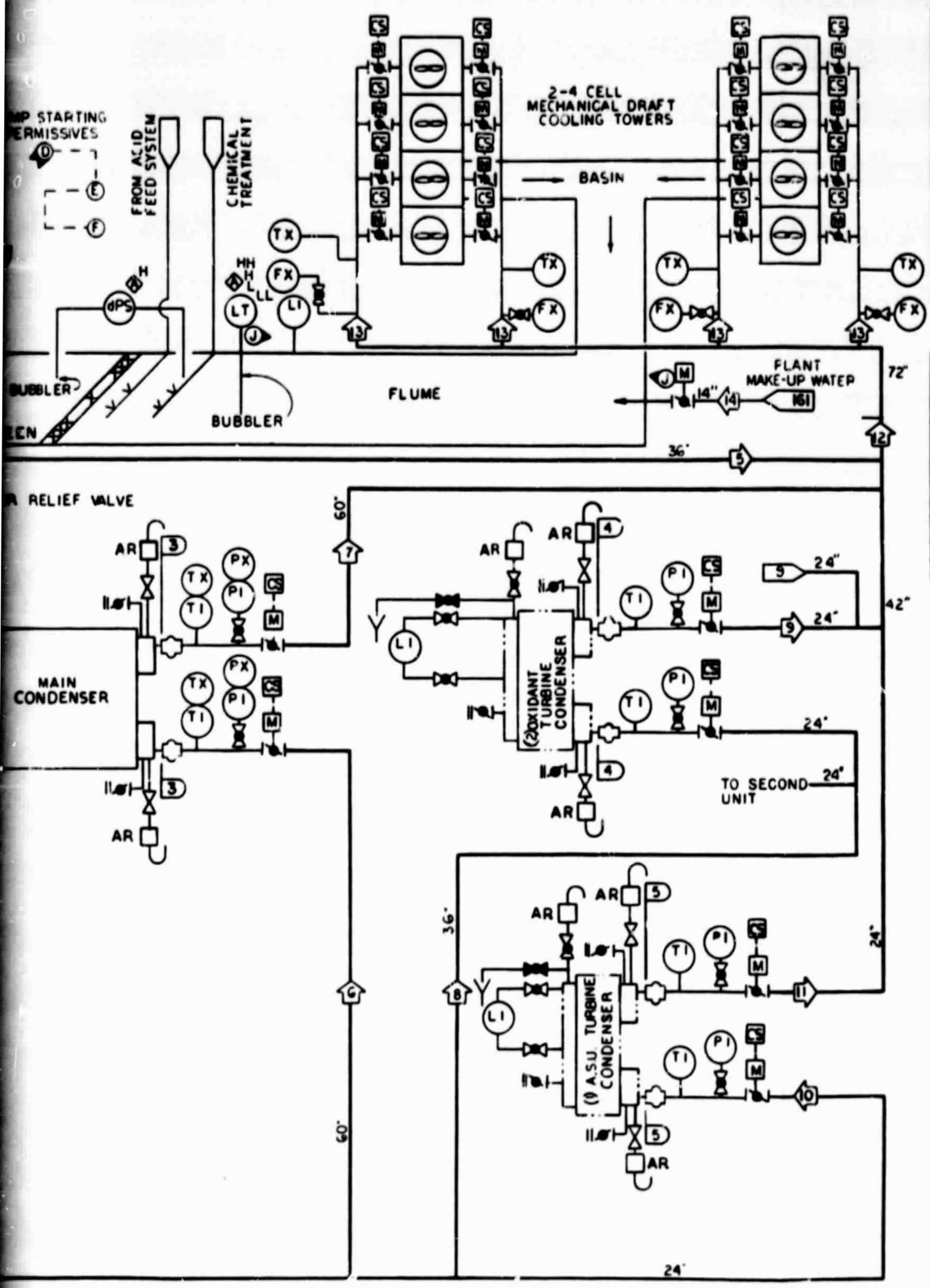
REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Condensate
Plant Makeup Water
Sampling
Closed Cycle Cooling Water
Slag Management

Plant Heat & Flow Balance Diagram	
System Heat Balance	8270-1-540-314-001


10
9
8
7
6
A
B
C
D
E
F
G
H
72"
72"
54"
36"
24"
PUMP STARTING PERMISSIVES
FROM ACID FEED SYSTEM
SERVICE WATER PUMPS
3-50% CAPACITY
CIRCULATING WATER PUMPS
3-50 / CAPACITY
BUBBLER
SCREEN
TO COOLING TOWER
AR-AIR RELIEF VALVE
ASU COMPRESSOR INTERCOOLER
A.S.U COMP. AFTER-COOLER
3-TRANSPORT GAS COMPRESSOR INTERCOOLERS
MAIN CONDENSER
CLOSED CYCLE COOLING HEAT EXCHANGERS
PLANT HEAT EXCHANGERS
BLOW DOWN
TO SLAG HANDLING
351
CONDUCTIVITY
CONDUCTIVITY
ACID FEED CONTROL
FOLDOUT FRAME



OPERATING DATA

#	FLOW LB/HR×10³	PRESS PSIG	TEMP	BY	REMARKS	REV
1	20000	26	69		CIRC. WTR. DISCH.	
2	4000	26	69		SERVICE WTR. DISCH.	
3	40000	26	69		CIRC. WTR. MAIN	
4	8000	26	69		SERVICE WTR. MAIN	
5	8000	20	92		HEAT EXCH. OUTLET	
6	25,600	26	69		MAIN COND. INLET	
7	2[illegible]	20	92		MAIN COND. OUTLET	
8	[illegible]	26	69		OXIDANT COND. INL.	
9	6500	20	92		OXIDANT COND. OUTL.	
10	4450	26	69		ASU COND. INLET	
11	4450	20	92		ASU COND. OUTLET	
12	48,000	20	92		CLG TWR INLET	
13	12,000	20	92		TO COOLING TWR	
14	850				MAKE-UP WATER	

DESIGN DATA

#	FLOW LB/HR×10³	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	21,000	50	100		A 53 GRADE B	
2	4200	50	100		A 53 GRADE B	
3	42,000	50	100		A 53 GRADE B	
4	8,400	50	100		A 53 GRADE B	
5	8400	50	100		A 53 GRADE B	
6	26,880	50	100		A 53 GRADE B	
8	6930	50	100		A 53 GRADE B	
10	4,670	50	100		A 53 GRADE B	

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FOLDOUT FRAME

I.B. NO. C-373-022

DATE	RELEASED FOR	ENGR.
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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

CIRCULATING & SERVICE WATER SDD-201

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135

APPD. H. RIGO

DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

REVISIONS
1 | ADDED H. RIGO, DATE & SDD NO. IN TITLE BLOCK | 6-10-81

DRAWING NUMBER 8270-1-571-302-201 REV 1